Politecnico di Torino

Corso di Laurea Magistrale in Ingegneria Gestionale LM-31

Manufacturing Know-How Management System for Product Development within the framework of Product Lifecycle Management

Supervisor: Prof. Franco Lombardi

Co-supervisor: Dr. Luigi Panza

Candidate: Ibrokhimjon Khamidov

Abstract

Today in a technical industry, Product Lifecycle Management (PLM) plays a major role which covers the mechanism of managing the whole lifecycle of a product from the beginning, via engineering design and manufacturing, to utility and conveyance of produced output. PLM combines business actions, data, people, processes, and hands over product information keystones for firms and their projects. Even though the PLM framework has been efficiently implemented in large and technological firms, its data management and the speed of its product development processes are a headache for the currently fast-changing industry. To be more definite, current product design applications do not support quick and efficient product development within its data management system. Additional challenge in small-medium enterprises is that IT infrastructure and new information system tools play a crucial role in the management of PLM, ERP, and MES and their integration.

The purpose of this research is to analyze the characteristics of novel cloud-based platforms (that could be used in managing the whole product data, engineering design, manufacturing process, and business processes) to boost possible know-how management systems for the product development system. In addition, an integrated framework for MES, ERP, and PLM systems in open-source object-oriented software known as ODOO is described in this thesis for the implementation by engineering industry firms. To this end, the aim is to provide a strategy to modernize the firm's IT infrastructure by enhancing the flow of data and increasing productivity.

In this work, firstly, primary sources of obstacles in traditional product design systems and product data management systems were identified within the structure of PLM by covering its four phases. Afterward, for each hot point of problems, possible solutions and methods are described utilizing the product development cloud-native platform. The results of this study were analyzed to demonstrate conceivable efficiency together with its probable negative and positive effects that can come up in a new desirable expertise management system for product development. Thesis is mainly separated into six parts by considering obstacles in traditional product design processes and subsequent problems in the current product data management system. Furthermore, the cloud-native platform’s achievable solutions are given, and all the possible consequences are investigated.

CONTENTS

Contents

LIST OF FIGURES

LIST OF ABBREVIATIONS

ERP	Enterprise Resource Planning
MES	Manufacturing Execution System
PLM	Product Lifecycle Management
CAID	Computer Aided Industrial Design
CPM	Critical Path Method
CAP	Computer Aided Production
CAPE	Computer Aided Production Engineering
MPM	Manufacturing Process Management
BOM	Bill of Material
ECO	Engineering Change Order
IIoT	Industrial Internet of things
GUI	Graphical User Interface
NPI	New Product Development
ECM	Engineering Change Management
CE	Concurrent Engineering
SME	Small Medium Engineering
SaaS	Software as a Service
PaaS	Platform as a Service
IaaS	Infrastructure as a Service
PBI	Product Backlog Item
SCM	Supply Chain Management
FEA	Finite Element Analysis
MRP	Material Requirements Planning
CSV	Comma Separated Values
SQL	Structured Queryy Language
CAE	Computer Aided Engineering
AR	Augmented Reality
R&D	Research and Development
AI	Artificial Intelligence

OKP	One-of-a-kind Production
CNC	Computer Numerical Control
ODOO	On Demand open Object
ISA	International Standard of Automation
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
PDM	Product Data Management

PART I: MAIN CONCEPTS AND PROBLEMS REGARDING PRODUCT DEVELOPMENT PROCESS WITH TRADITIONAL METHODS

1. INTRODUCTION TO COMMON PRODUCT LIFECYCLE MANAGEMENT

Product lifecycle management allows systematically managing the entire lifetime of a product and the data connected to it, starting from design until the order-delivery process of manufactured products to customers. PLM has an integrated approach to product management. It is an activity that deals not only with items but also with organizational structures, work techniques, processes, people, data structure, and ISS (Information Security systems) [1]. Therefore, the efficient organization of those steps is in favour of the success of industrial firms.

1.1 BASIC PLM AND MAIN PDM CONCEPTS

In current market conditions, products have many varieties, including tangible (physical) goods, intangibles such as software, algorithms, and services, which are marketable. PLM is a deep business conceptuality used to handle the entire product life cycle, covering not only goods, documents, and bills of materials (BOMs), but also result from analysis, test processes, quality management, engineering scope, manufacturing processes, product achievement data, suppliers of parts, program management, project control features, workflow, and so on [2]. (Figure 1)

Figure 1 The simplest imaginative view of the PLM system. Image from Beyond PLM (Product Lifecycle Management) Blog PLM360 and Fusion Lifecycle Trajectories - Beyond PLM (Product Lifecycle Management) Blog. https://beyondplm.com/2016/05/18/plm360-fusion-lifecycle-tr

Until current days, PLM's purposes have stayed unchanged for manufacturing companies, and this list can go down for eternity, but the main purpose of increasing its efficiency always stays as a key factor.

Automation of product data management and integration with other business operations like Manufacturing Execution System (MES) and Enterprise Resource Planning (ERP) may be conducted with this platform, resulting in superior customer products for the firm [3].

- Reduce time-to-market
- Increase in revenue or ROI (return on investment)
- Cut waste and get a good framework for product optimization.
- Innovate quickly.
- Effective re-use of previously created designs
- Seasonal quick adaptation management
- lower prototyping costs and legal documentation compliance
- The facility will provide firms with quick access to central record data.
- Fast product development

In the era of digital technologies, the smooth flow of data plays the main role in the entire process. The issue related to that is product data management (PDM), which is a subset of PLM. Engineering companies utilize CAD (Computer-aided design) platforms for product design processes. For the high volume of data generated during those procedures, we need PDM regulations for effective management [2], [4]. Strong PDM induces the establishment and keeping track of product development processes through powerful document revision levels, control of BOM, increasing reutilization of existing product information, reducing the risk of wrong design versions, sharing, and excellent data storage security. As information that is created by the company's skilled employees is great capital for the firm itself, it should be accessible in any place, at any time, and within any time frame.

1.2 Phases and business case for market lifecycle

For clarity, the steps are depicted in a traditional sequential engineering progression. The accurate turn of events and work will differ relative to the industry and products [2]. In reality, due to manufacturing requirements and conflicting requirements, it is more complex, whereas

some people and departments are not able to perform their own tasks in isolated form, and one task cannot easily finish and succeeding action starts.

1.2.1 Phase 1: Preliminary planning or Conceive

The specification and concept design phase begins with the specification and concept design. It

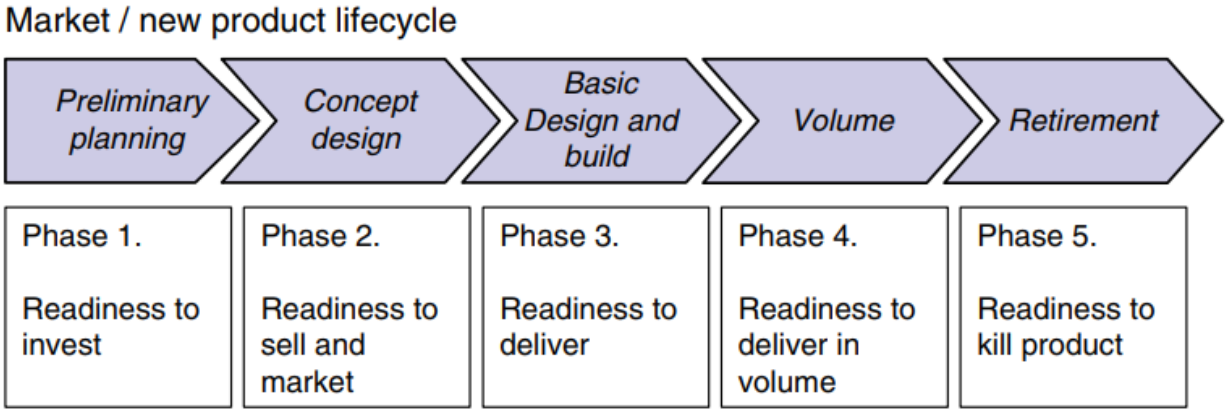

Figure 2 Common Five Phases of Product development process. Image from 'Product Lifecycle Management - A. Saaksvuori, A. Immonen'

also consists of defining product requirements from the viewpoints of customers, companies, the market, and regulatory bodies. Planning is done through clarifying customer segments, sales/delivery channels, product variables, production methods and scheduling the product's design, manufacturing and marketing processes [2] [5]. Defining and estimating the product's target cost, selling price, and volume are also critical steps in the planning process. Many various applications are used for those procedures, from pencil and paper to 3D CAID (computer-aided industrial design software) software.

1.2.2 Phase 2: Concept design

This is where designing the basic product subject to target schedule and costs gets done. An approximate cost estimate is used to evaluate if the basic product concept has been designed to fit the target cost and estimate the most critical cost and schedule variables to do the risk analysis [2] [5]. By verifying the market and demand, the business entity will be ready to sell and market the products.

1.2.3 Phase 3: Basic and detailed design, Build product:

Prototype testing is the third step, which is proceeded by pilot testing, full product launching, and final product design and development. It involves making adjustments to existing processes or starting from scratch to get better results. CAD (computer-aided design) software is the primary tool for developing 2D and 3D designs for new products. As an example, hybrid modelling software utilizes non-destructive testing, reverse engineering, and knowledge-based engineering, as well as assembling techniques. CAE (computer-aided engineering) software is used to simulate and validate activities including stress analysis, kinematics, and computational fluid dynamics, among others.[2] [5].

1.2.4 Phase 4: Volume or Realize

When the complete design of product components is ready, the methodology of manufacturing is defined. This includes CAD jobs such as tool design including CNC machining instructions for the product's parts. By using CAM (computer-aided manufacturing) software, specific tools are

created to manufacture those parts. Some simulation operations regarding manufacturing processes are carried out, such as casting, molding, and die-press forming. If the ways of manufacturing are clarified, CPM (critical path method) comes into production. It is made up of CAPE (computer-aided production engineering) or CAP/CAPP (computer-aided production planning) tools for the plant, factory layout, and production simulation [2] [5]. Focus is also given to volume production such as BOM cost-cutting, MPM efficiency, delivery cost efficiency, verifying schedule, margin, and pricing. After that, it will be ready for volume delivery and additional services (maintenance, support, recycling, sustaining, repairing, etc.).

1.2.5 Phase 5: Retirement

Once the product matures and demand is low, its service and production are forced to decline systematically following the demand curve [2] [5]. Then a new product development process is launched from the beginning.

2. Common Issues in preliminary planning and Concept design (Phase 1 and 2)

From now on, some frequent challenges will be discussed and analysed regarding Phase 1 preliminary planning and Phase 2 Concept design.

2.1 Defining product requirements

Generally, when a company wishes to launch a new product development, they often do it through their marketing departments and the feedback they collect from customers. However, the product is not developed by the marketer or the customer itself. Only engineers make an effort to do so. Therefore, the desires of customers frequently do not match the imaginations of product engineers. The problem is about clearly defining what the customer wants and matching their desires even if their requirements change over time regarding the product [2] [6]. There is no transparent and strong bridge or management system between customers and product designers with little intrusion of marketers for effective collaboration.

2.2 Defining overall product strategy

Classical models of Michael E. Porter state that firms compete mostly on two basic strategies: cost leadership (a cost advantage) and differentiation (being unique). However, the problem with following strategies is that if you follow one strategy path, you usually compete with the same main strategy follower. For instance, a cost leader vs. another cost leader. Hence, a company limits its customer segment and, because of its capability, resources, product development systems, and other firm factors, it has to go down one strategy path. They were successful in implementing both strategies with their own systems within different departments, primarily in the textiles (INDITEX), software, and furniture (IKEA) industries [2] [4].role is mainly played by specific production tools that help to align both strategies. Therefore, the question arises. Is there enough of any product development system (mainly in the engineering sphere) which is able to integrate both two types of strategy for competitive advantage?

2.3 Importance of Time

In a recent study of big firms by Aberdeen Group, the need to speed up product design and manufacturing was identified as the greatest competitive pressure [7]. (Figure 3)

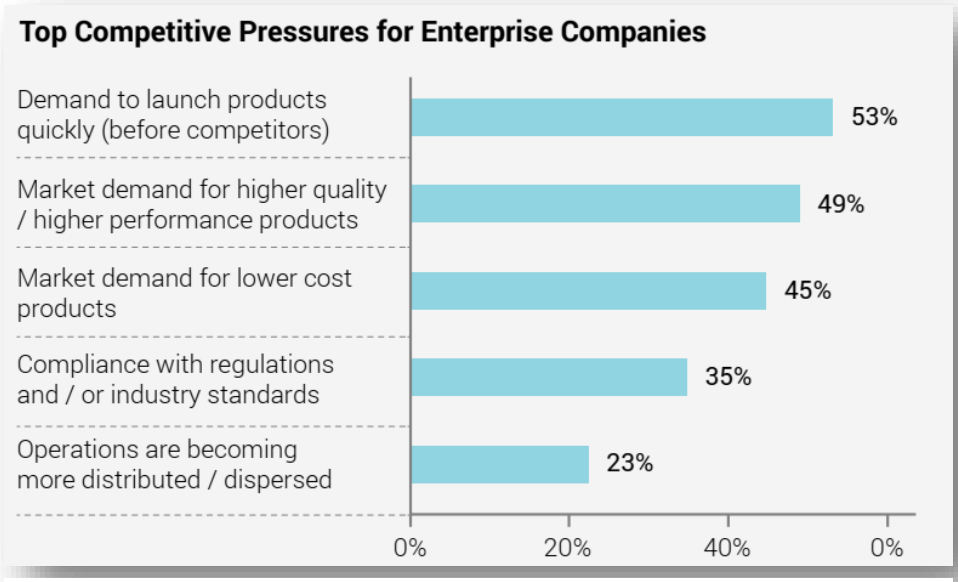

Figure 3 How the speed of product development and market introduction are essential. Statistics from 'Introduction to Agile design, W.Need,2019'

Time-to-market is the time required to bring a new product to the market, or in other words, the turnaround time for the NPI (New Product Introduction) process. If it is too long, it leads to a direct loss of market share, earning potential, and competitive advantage [2]. The firm's competitor entered the market before the company itself, and the current NPI may not be able to meet the demands of today's business needs.

Time to react. A problem arises when the firm is unable to react quickly enough to changes that are happening in the market, in the supply chain, in technology changes or customer demands. When there are mistakes in products or their designs, firms with poor product development systems will be unable to respond quickly to their faults [2]. Current PLM systems are unable to give support for responding quickly to market demand. Modifications to several products are carried out slowly and are not done simultaneously to shorten the time for response.

2.4 Management aspects

Through the management part, some challenges of management decisions and project management disciplines will be discussed as briefly as possible, which are related.

2.4.1 Project management methodologies

Most current enterprises utilise standard methods for planning product development processes that cause delays in tasks. A small amount of work can sometimes take weeks, months, or years [2] [4]. Innovation can require **working around** processes and tools. There has to be a way to develop products speedily and by differentiating innovatively.

2.4.2 Challenges in Finding Group members in the local area

Within the product development system, every project consists of various stages, whereas each stage requires different expertise. Discovering requested staff for projects within the local area is always an effort. Only a few people will have knowledge of programming, system integration, database management, or all the business processes of the firm, including engineering design,

product development, manufacturing, sales, and marketing with the required skills. The project group is responsible for all possible challenges throughout the enterprise.

In particular, for engineering companies located in areas with limitations, it is hard to discover those types of workers with excellent communicative skills when one worker leaves a firm [2].

2.4.3 Traditional CAD's way of adding new team members and monitoring team

Moreover, many engineering managers claim that there is a 2-to 3-week wait to bring new team members onto a project, and it is necessary for the department to deliver a new computer and then install traditional CAD and PDM software.

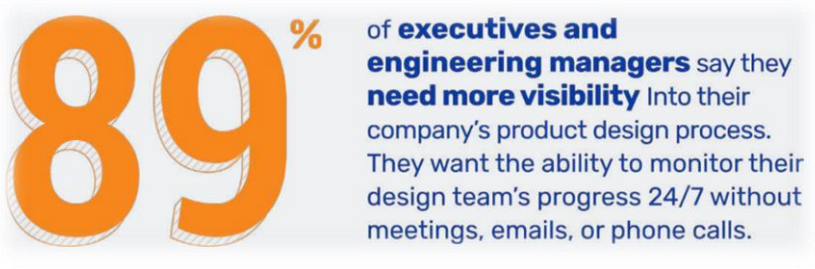

Figure 4 Aberdeen Group research result. Image from 'The engineering leader's guide to PDM, 2020 '

Therefore, new members cannot instantly start working on the project. The first step in controlling a new computer with an installed CAD application is clarifying if you need another licence code. If the licence is the floating type, it is sometimes a hiccup to find an additional licence for a new member. If you need to buy a new licence code, it is necessary to make a purchase request that can take days or weeks, depending on the value-added reseller (VAR). After getting the licence code, it can take several hours to install just one device. However, what if an onsite team member (in Paris, New York, etc.) or contractor needs CAD and PDM software and files? The problem becomes even more complicated with additional costs and time [6] [8]. Another issue that many engineering managers face is that they need more visibility to control what teams produce. Members of a company are carrying out their duties. Widespread ways of doing that are usually time-consuming and require some effort.

2.4.4 Gaps between executives and engineers

The view from the top often looks different from the view from the trenches. There is a disconnect between executives and individual contributors about their largest issues in product development. A survey taken of almost 1000 respondents (engineers and executives) demonstrates those gaps among each of them [8]. These results can be interpreted in one of two ways.

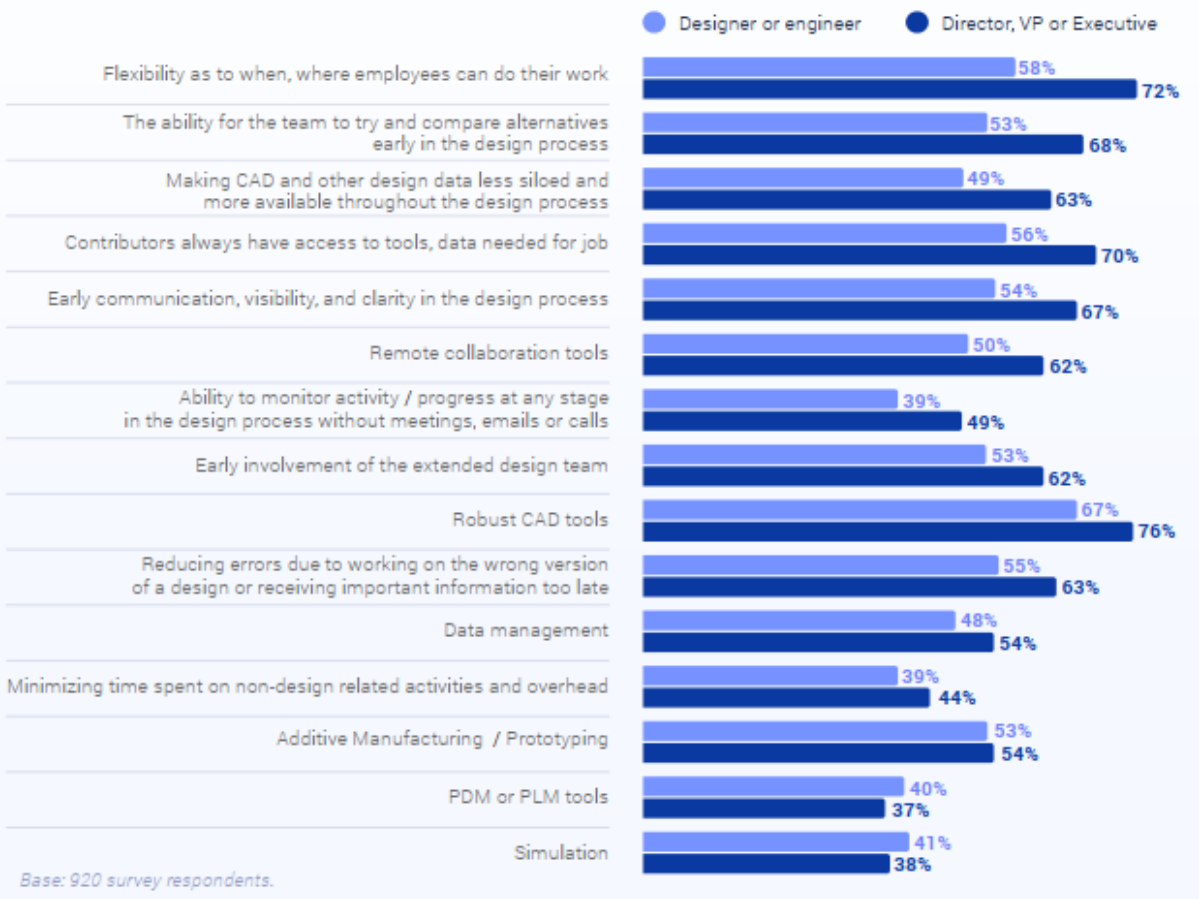

Figure 5 Current capability ratings by product development role. The bars show measure the percentage of respondents who rated their company "good" or "excellent" in each category. Data from 'The state of product development hardware design, 2020'

1. Designers and engineers are more sceptical of their company's current capabilities.
2. Executives have an increased view of their enterprise's current abilities.

Specifically, the gulf between executive perceptions of their technological abilities and engineers' assessments might lead to systematic business challenges involving unrealistic expectations such

Figure 6 Different gaps between executives and engineers. Data from 'The state of product development & hardware design 2020'

as delivery on critical task deadlines and client requests [8]. These results ought to cause concern for product development leaders. Significant gaps in perception about firm culture, access to new technologies, and collaboration quality should be the primary goal for problem-solving. Additionally, younger employees or junior-ranked employees are often inclined to make errors, and they need a flexible work environment.

2.4.5 Different applications for project management and planning within PLM

Large projects require the utilisation of different software types for diverse types of activity in management. There might even be up to 50 distinct apps in a standard-sized firm. PLM apps allow individuals to build products and support them. It appears unlikely that such sophisticated and precise goods can be produced without these uses. There are some common examples, such

Figure 7 Distinct PM tools. Sources are from official company's websites

as Microsoft Project, ProofHub, Microsoft Excel, Trello, Workzone, etc. Some are convenient for risk management for approximately measuring the amount of contingency budget and analytical graphs, and some are useful for monitoring and execution of product development projects [9]. The main issue is linking all those phases of a project into a unique software that could help manage projects easily.

3. Common issues in Basic & Detailed design and Manufacturing (Phase 3 & 4)

This is where the detailed design and development of the products form initiates, with progress to prototype testing, via pilot release to complete product launch. It may also include redesign and ramp for existing product improvement, as well as planned obsolescence [1] [2] [4]. The

main instrument used for design and development is CAD software with simple 2D drawing or 3D parametric solid/surface modelling. In this part, we will discuss and try to analyse common issues that arise in the design process.

3.1 Different locations and External design teams

Traditional file-based CAD software was developed for teams that worked together in one building. The creators of those applications did not expect the globally spread and instantly fluctuating current teams to be well organised into well-organized PLM systems. Not all types of CAD allow several people or geographically different organisations to work with the same CAD, and it is challenging for them to see each other's engineering work [7]. The current pandemic situation of COVID-19 with social distance precaution, in particular, demonstrated how traditional CAD applications are vulnerable to such conditions. Moreover, it does not allow the outsourcing of the workforce for cheaper or more qualified ones.

Figure 8 Common CAD applications allow working in one location. Image from 'An introduction to agile product design by Onshape, 2020'.

3.2 CAD software and factors in whole design processes

As the main tool for the execution of the design process is CAD application, some general and frequent problems will be mentioned and discussed.

3.2.1 Update, Maintenance,

Most current applications of CAD always need updating, installation, and maintenance for effective functioning, and it is costly for firms. For small-sized companies, CAD workers become CAD administrators who will be responsible for those tasks rather than spending time on their professional design tasks. For new team members, you may need to install an additional licenced CAD application [5]. Testing is done in a controlled environment before the deployment of new software. It will require extra hardware, time, money and IT resources.

3.2.2 License

Typically, licences are either "named" or "floating" (concurrent, network): the quantity of floating licences is determined by the number of system users, whereas named user licences are assigned to specific tasks or functions or specific individuals within a company [10]. When an authorised user wants to run the application, they request a licence from a central licence server, which is a common issue in floating ones. If there is a license, the programme can be launched on the licence server [11]. So a local licence server is required at every user's location, and each device or PC needs to connect to it. License files need to be linked to host IDs. Hence, the number of licences installed on the licence server curbs the number of concurrent users.

The problem with named licences is that everyone who uses the system has to have a licence for each specific task, which requires some cost, time, and effort to manage. The disadvantage of named licences is that named user licences are associated with specific user ID's. This limits the licences to being checked out only by specific users.

For both types, a yearly maintenance fee has to be paid for licenses, which is typically called a support payment. The price varies, usually from 15% to 20% of the software licences [2].

3.2.3 Hardware acquisitions

For managing the whole system and files created by CAD and other business stakeholders, local PLM servers are required and a strong network among distinct locations. It demands additional maintenance and safety conditions for future usability [11]. Overall, there is a need for money, staff, and additional areas for keeping servers.

3.2.4 Operating problems/technical errors in the software

The software industry is often blamed for the fact that it allows some mistakes and illogicalness in its products. However, for some motives, these tend to be called "mistakes" but rather "features" or "properties." Many software settings or parameters must not be wrong before the desired result is obtained. This kind of trouble or risk usually arises when the system is updated to newer versions [11]. Problems also occur because of a lack of expertise by users or actual errors in applications. In the end, software error problems appear in the whole PLM software by creating frictions in the system and loss of essential data.

3.2.5 Distinct CAD software

In the era of strong competition, different companies use different CAD applications for their product design processes. This is because, for historical reasons, they formed their own specific systems, and the diverse fields of design and engineering have very different needs. Furthermore, the firm's IT strategy may be different. In addition, many companies outsource their design and production to diverse subcontractors and suppliers. This also induces the need

Figure 9 Diverse types of CAD applications pictures from Google images

for careful attention to applications used by subcontractors. Therefore, the great amount of software makes its integrated use very challenging, and it is difficult for engineers and designers to move onto other software types when required. Many of them have different functions and visualization, especially if vendors of applications are completely diverse. However, it is sometimes possible to come across some similar-functionality CAD applications that are mainly created by the same vendors.

3.2.6 Approval of CAD documents

Usually, the release of drawing documents and approval of them are manually acknowledged with pen and paper by responsible authorities. These kinds of typical activities are still used in different old-structured companies. Even though they use CAD software for drawing, the approval process is not accomplished, unless the printed version (2D) drawings of CAD documents are delivered to inspecting individuals before the start of the project [11] [6]. Moreover, when engineers complete their drawings, they have to contact the approving senior engineer with separate communication systems (email, phone call, etc.), which are not integrated into the CAD software. Overall, current CAD software does not allow efficient approval processes and causes delays in product development.

3.2.7 Commenting on or inspecting design through CAD

If a senior engineer finds some misalignment in the design of components, demonstrating and suggesting improvements to lower level engineers is usually done through manual action (being present in front of the engineer or writing comments on documents). It is typically hard to find convenient CAD software types that can manage commenting processes easily and provide comfort for senior engineers [12]. It is also critical that comments be registered and saved within servers to avoid confusion and clearly define responsibilities.

3.2.8 Opportunity costs due to unused gadgets

If the history of current widespread CAD applications is analysed, it will be clear that most of them did not expect such high technological advancements in the industry of smartphones, tablets, and the related popularity of software [13] (Figure 10). When most of the common CAD software types emerged over 20 years ago, all of them were supposed to be used for the

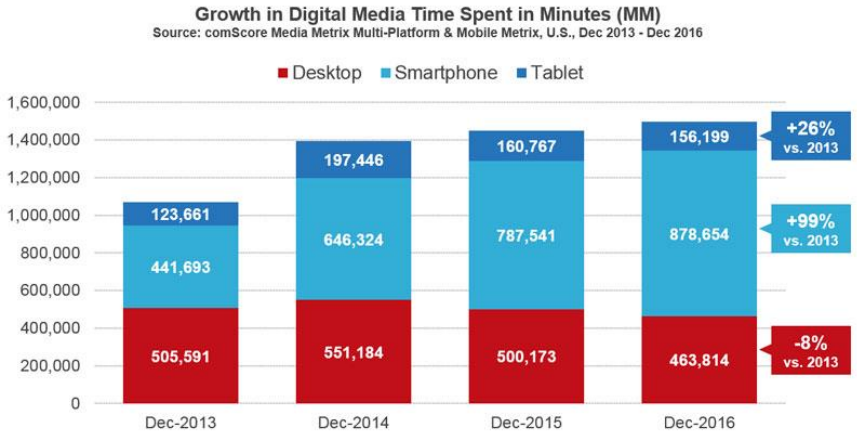

Figure 10 Graph demonstrating popularity of smartphones and tablets. Statistics from A. Lella, "Smartphone Usage Has Doubled in the Past Three Years - comScore, Inc," 27-01-2017, 2017

desktop, and there was no prediction that smartphones and tablets could become so strong with their hardware and operating systems such as iOS, Android, etc. They are usually easily portable and have many functionalities with the support of strong internet connections. Therefore, many new software-related startups generally develop additional applications for smartphones like PC software types to attract more consumers. The general problem with common CAD applications is that they do not utilise the current advanced functionalities of smartphones and tablets that could overcome most deadlocks in operational processes, even small ones. Even if they wished to do that, it would be challenging for them as many CAD applications are too complex and many smartphones may not be able to handle it. There must be a golden midpoint that could support solving the problem, but the role and opportunities of smartphones should not be left on the desk.

3.3 Other issue factors in design processes

As mentioned above, time to market is an essential factor for competitive advantage and more time to build market share by facing initial market competition. Speed is not fully crucial for the sake of it, and it is not about madly rushing as fast as you can or using your authority to make employees work harder. It is about removing invisible time-wasters or generating a system that pushes workers to increase their speed, creating time to breathe and exploring alternative and innovative ideas [6] [14].

3.3.1 Negative aspects in sequential product development

Many product development processes require sequential order for design. If one designer is working on a specific component, another engineer has no access to the drawing file for better quality work. This is due to the intention of controlling everything, and it consequently leads to lengthening time [7]. The problem is mainly a concern of the concurrent engineering (CE) field, which tries to govern all the steps of the product development process synchronously and to focus on reducing the development process and decreasing development costs by preserving high quality [2] [6]. For instance, common product development platforms do not permit one person to work or edit a particular file simultaneously with another worker. In other words, only one person can do a change or design process at a time, while others are not able to intervene. Sequential workflows lead to a lack of information sharing, a less productive environment, and even a loss in the quality of developed products [15].

Figure 11 Sequential work which takes more time. Image from ' An introduction to agile product design by Onshape'.

3.3.2 Communication and exchange of files during the design

Daily collaboration mainly includes acquiring information, the creation of files, transfer of data and exchange of information, and granting information about modifications, for example, via the PLM system. E-mail, unstructured databanks on the network, fax, and telephone are not compatible communication tools for organised cooperation [2] [11]. Furthermore, Allen in his research for many years found that communication within employers' affects the quality and speed of their work [6]. He concentrated and demonstrated the effectiveness of face-to-face contact, whereas online communications were inexistent during his research periods.

3.3.3 Wasted time for non-productive stuff

When it comes to product development, a significant conclusion was that cutting down on time spent on non-design-related chores like data management, IT support, and communication with co-workers is the most pressing issue.

Designers and manufacturers produce the intellectual property (IP) that keeps enterprises alive or kills them. Huge quantities of resources are devoted to the search for the next great idea. It costs money and prolongs the time it takes to develop new products when the technical staff isn't working on them. Wasted time allows business opponents to catch up or surpass companies in the market if they aren't squandering their own time. In other words, what are the activities that "take" time from the designer? Let's see what can be found?

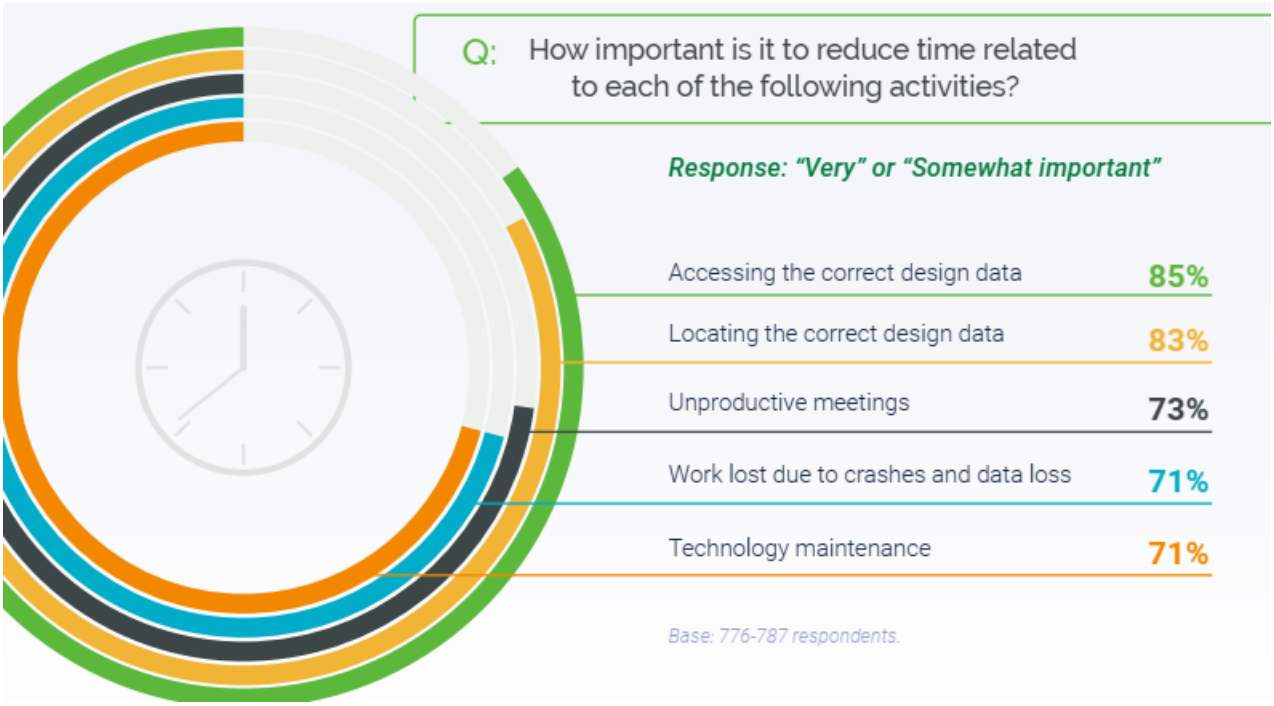

Figure 12 Activities that take time from engineers. Data from 'THE STATE OF PRODUCT DEVELOPMENT & HARDWARE DESIGN 2021'

3.4 Change management problems

During design processes and sourcing, the company frequently makes quick and uncontrolled changes in the design of the product with some claims (for reduction of costs, documentation errors, design errors, product improvement by customer feedback, or making a new version). Hence, these uncontrolled modifications lead to errors in component procurement and useless part stocks and it will be hard to co-ordinate those changes [12]. For items manufactured inside the company, this can lead to problems with tools and jigs, as well as planning CNC applications. Change processes are ordered in PLM systems and there may be their own strict regulations for the security of component design versions [2] [1].

3.4.1 Mistakes of design and Resolving faulty product

Therefore, some illegal configurations are made, and consequently, it leads to faulty products being delivered to the customer and eventually a bad reputation. Those faulty products must be improved during manufacturing or even after delivery to customers at the premises. Furthermore, most Computer-Aided Design software is not able to recover from the mistakes made and return to their previous condition. This issue is more related to the PDM part [11]. The quality costs come from direct material waste, from wasted manufacturing parts and assembly work, from returns of manufactured products, from claims, from repairs under official guarantees and from the reduction in the value of the trademark.

3.4.2 Change approval

As mentioned above, in primary design processes, approval of documents plays a crucial role in shortening time-to-market. There are Engineering Change Management (ECM) processes and systems to monitor any changes that might be necessary sooner. Nevertheless, in the common environment, these systems are often bureaucratic, paper-intensive, complex and time-consuming. A central engineering services group may have the responsibility for modifications, but they do not own the tools for pushing the change processes as quickly as possible. Several

departments generally take part, which might result in the proposed modification being authorised and included in the product design, taking several months and 50 or more distinct papers [11]. Even though the modification was agreed upon and announced, many months might pass by before the corresponding documentation got to the field. Although the change process takes months or weeks, the actual processing time could only have been minutes or hours. The rest of the time was just wasted.

3.4.3 Change management effects on sub-contractors

Change management is usually difficult for many sub-contractors, who cannot utilize the principles of concurrent engineering (CE) or parallel engineering. When some changes are done, the other side must be acknowledged in parallel about modifications.[2] When there is such confusion, it easily induces the production of wrong parts, material waste and extra cost for the company. The management of documents coming from subcontractors is usually problematic as materials contain a huge amount of CAD documents due to several types of formats used by subcontractors.

3.4.4 Commenting and communicating on changes

Even if their systems are connected to the systems of clients, it is commonly problematic to notify them about changes in component design [16]. For instance, if some modifications are carried out in the design of one component, it is hard for current CAD or PLM software types to warn or clearly explain to other parties (sub-contractors, suppliers) about these changes quickly and effectively. In many CAD applications, there is a lack of visibility and communication capabilities.

3.4.5 Configuration

During production processes, some specific clients wish to change or customize common products based on their needs through configurators. Configuration is the methodology of arranging or, in other words, a configurator in IT is an application that manages a product's variations and structure. Different configurators have various operations and content. For instance, in sales configuration for a selected car on a property level, it would be as follows:

- Chassis of the car: a three-door coupe
- Engine: 50 kW
- Gearbox: automatic
- Colour: red

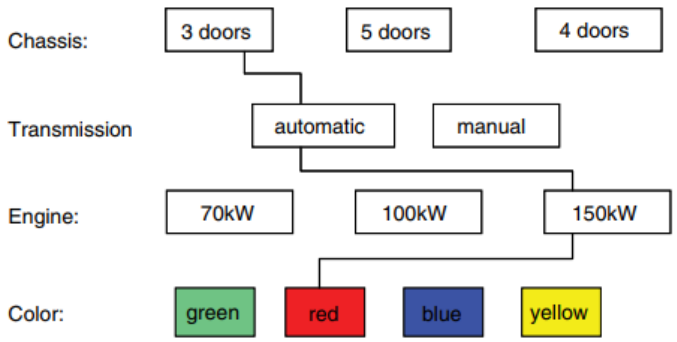

Figure 13 A practical use of configuration. Image from 'Product Lifecycle Management - A. Saaksvuori, A. Immonen'

Based on the chosen sales configuration, a materialistic product structure can be manufactured in the production system with those items and their variations. This demonstrates that production systems, or for example, CAD, should own product structure configuration features for efficiency. However, not all PLM applications do hold those customer-required properties [2]. Sometimes, that configurator is an independent or separate application that is not integrated with the PLM system. In reality, products have thousands of parts, which makes it more challenging for management to make different variations of products on time and change products.

PART II: PROBLEMS RELATED TO PRODUCT DATA MANAGEMENT WITHIN PLM

6. Preliminary definition of Product data and their issues

The definition of product data states that it determines the physical and functional features of the product-i.e., the fit, form, and function of the product. The product model principles and the product model or data for which the word product structure is always strongly associated with product data, as it is also connected with the abbreviation of BOM (Bill of Materials) [2]. In this part, we will discuss the challenges faced by the firm corporate during product data management.

6.1 Distinct issues with product data

The part will mention each type of difference that usually appears in product data and their negative effects.

6.1.1 Different usage purposes

The application of the information, in which the data is saved and recorded, varies. Information about products might have been produced for distinct goals or in some other linkage. However, it should still be usable in other tasks rather than those for which it was produced [2]. For instance, using product structure data in e-business that is created in the design phase.

6.1.2 Different formats of product data files

Nowadays, many CAD software types save created 2D/3D design documents in different formats. It causes confusion and misalignment when the firm's suppliers use different CAD applications (NX Siemens, SolidWorks, AutoCAD, Compass, CATIA, Autodesk Inventor, etc.) and keep files in different formats, which are not compatible with the software itself. Formats can be of various types and there are some examples:
.3DXML,.3DS,.MAX,.SAT,.ASAT,.SAB,.ASAB,.DWG,.DXF,.FBX,.CATPar,.CATProduct,.IGS,.IGES,.ICS,.IPT, IAM,.PRT,.G,.ASM,.PSM,.SLDPRTAs expected, there are several formats. If one company changes its PLM structure and starts to use diverse product design software, it necessarily needs to move all product information into the databank (servers) that are connected to new CAD applications. Of course, there will not be a definite guarantee that the format of the previous data suits the new one [17] [18].

6.1.3 Different Product structures

A product structure can be of two types: relational and hierarchical. It all depends on the ability of product development systems to maintain diverse versions of product structures or bills of materials (BOMs). The BOM hierarchy helps to analyse and examine large and complex product

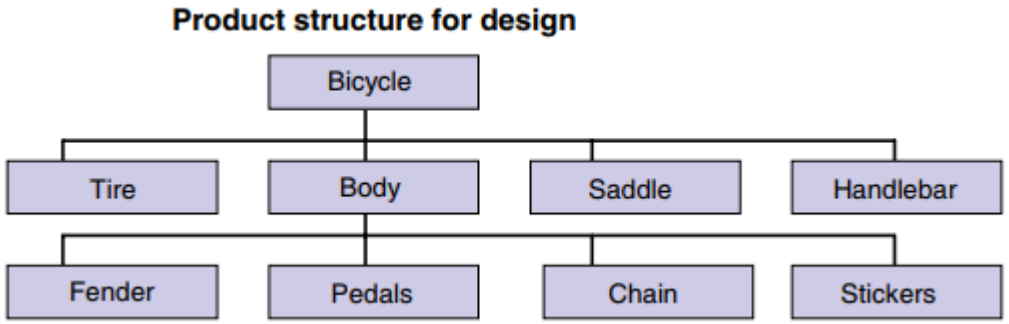

Figure 14 BOM structure from engineering point of view. Image from 'Product Lifecycle Management - A. Saaksvuori, A. Immonen'

models. A product tree for design purposes may be different from a product tree for manufacturing purposes. Because typical ones do not support these kinds of functions, and some handle them with few restrictions, PDM systems should be able to manage different types of product structures for different purposes.

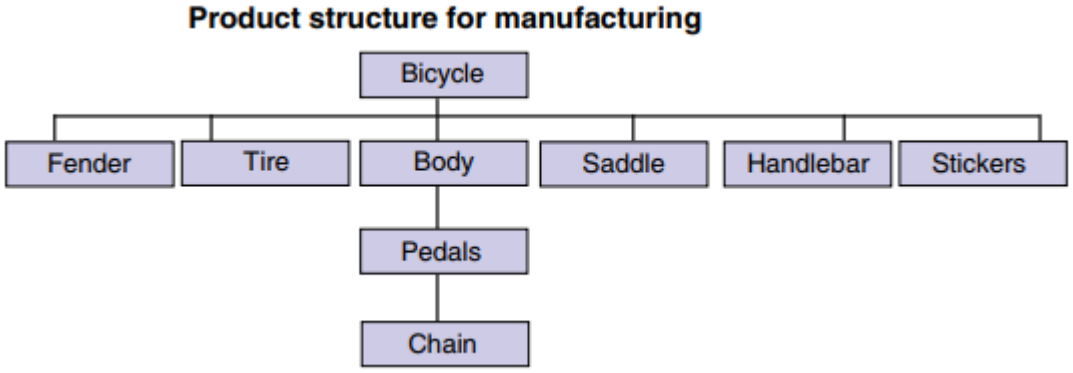

Figure 15 Product structure from the manufacturing point of view. Image from 'Product Lifecycle Management - A. Saaksvuori, A. Immonen'

In addition to being hierarchical, many old PDM systems are not capable of holding extra relations among product components or items due to the constraints of database systems [2]. For example, a car has multiple types of sensors and there may not be a class named "sensors" which keeps all the types of sensors that belong to the firm's database.

6.2 Items

An item is a standard and systematic method to identify, name and encodes a product, product part or its structure, component, service or material. They are also used to identify documents and form separate classes, subclasses and groups according to international standards. Oppositely, excessively definite classification slows down operational processes and significantly pushes up the amount of work required to maintain the items. Sometimes a firm's component stock consists of a large group of component items, which are self-manufactured components or components to be bought. Some disorders of item management induce the problem of creating new items rather than finding them in item management systems. It causes multiple creations of copies of similar items in the system, causing difficulties and loss of time in searching.

Furthermore, the structure of the item hierarchy has to be documented and, in addition to connections and hierarchies among items and item classes, international standards of creation and unification must be taken into account. On the other hand, there can be large distinctions in item areas and item coding schemes among the detached business units of these firms [2]. So, totally coincident and uniform numbering and encoding is not always the right choice, and additionally, unification of large item bases may be very laborious.

6.3 Vicious circle of deteriorating product data

Quick changes in the business environment and an increase in the variations of products have made it challenging to maintain and find product-related information. The complexity of

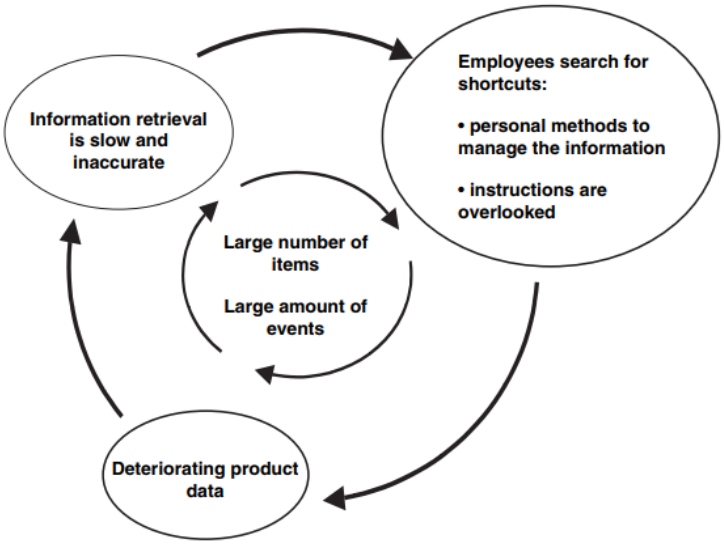

Figure 16 Vicious circle of deteriorating data. Image from 'Product Lifecycle Management - A. Saaksvuori, A. Immonen'.

products is increasing; decentralised and global organisations have fallen into a vicious circle, where there are a large number of items and a huge number of laborious assignments. Information retrieval is not speedy as the data is scattered over different systems or on the PCs of employees.

Updating the data becomes problematic, inaccurate, and irregular, which leads to a situation where engineers cannot trust the product information in the management of a company. Part of the information might be recorded inside the notebook of an employee, and if there are no codes for transferring files, the employees will create their own methods for that. The circle causes the material to disintegrate more and more [2].

7. Issues in Repositories

Several enterprises tend to keep their crucial data using multiple methods, from paper documentation to databank servers and internet cloud servers. In the following sections, some issues in managing databanks and information-saving methods will be discussed.

7.1 Paper documentation

In some firms, paper documentation is still used for regulatory reasons, where paper versions are filed in drawing archives and they are considered as official or original versions of the documentation. Problems usually occur when the official paper document does not correspond to the version inside the file. In this case, there will be a need for regulatory law stating that

whoever made the original drawing will also make any changes. Moreover, it is necessary to have space for keeping paper versions in an archive, and it is costly for any firm to follow this saving method. However, paper archives cannot be deleted virtually and require physical effort, and this causes prolonged belief in their utilization [2] [15].

7.2 Distinct database providers

Usually, PLM systems require one particular, proprietary brand from the system supplier or different databases to operate. However, most PLM systems support common SQL relational databases such as Oracle, SQL-Server Informix, MS, Progress, DB2 or Sybase [19]. Environments for systems, including the usage of many diverse database types, present bigger challenges to the PLM system and naturally to data transfer and integration between different systems. In addition, the relational database (usually called a SQL database due to the language useful for the capability of eliminating, changing, adding, and discovering data) keeps the metadata in unadjustable tables with fixed programmes and pointers connecting multiple tables together [6]. Consequently, this puts a burden on the capability that a database can do and also on the kind of data it can store [11]. In addition, each database application in the fundament of the system generally requires discrete licenses. The licence can be of two types: floating or fixed (processor-specific licenses). Floating licences (roaming licenses) permit several users to share software access to applications, whereas fixed licences allow use by only one user [10]. The number or strength of the processors on the server determines the price of the fixed licence type. Hence, it is costly for big enterprises to maintain, upgrade, or change the licence within the firm every time the application is upgraded by adding new functions [20] [1].

7.3 Depending on the individual worker

The product knowledge of the product development procedures heavily depends on the individuals in the organization. There are many employees with different special expertise, or there is a lot of information within the company. However, the firm may be very much bound to particular people who play the role as' hub ’in an enterprise becoming knowledge manager. They have a peculiar role within the scope of the firm and their absence can lead to the destruction of some project management and loss of knowledge in the company [2] [6].

7.4 Different approaches of data treatment in different departments

Different approaches by the parties concerned with the protection and handling of information or producing and storing the product data in different data media induce incompleteness and

inconsistency of information [2]. Each enterprise, when trying to retrieve data from its repositories, treats the same data in a specific way, and that can be ad hoc according to the

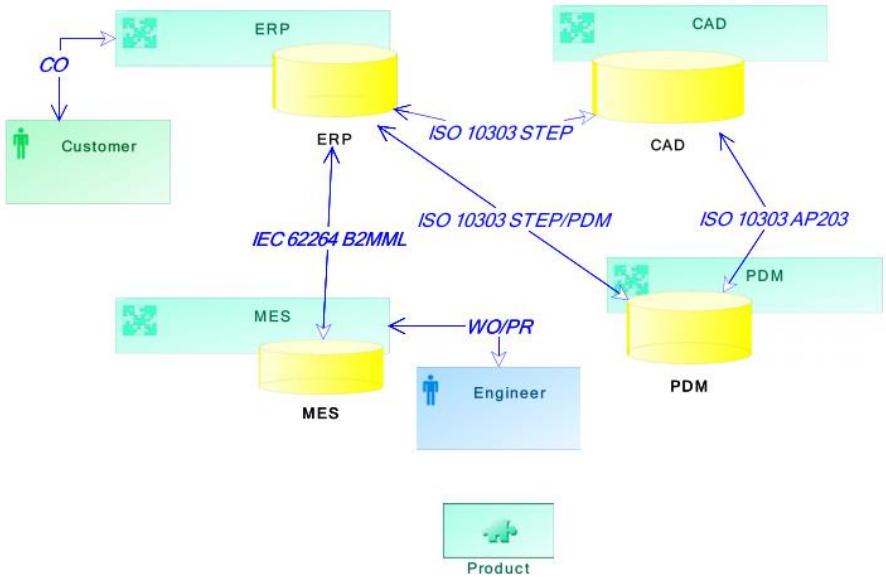

Figure 17 Treatment of data within diverse enterprises with rigid standards. Image from 'Product-driven ONTOlogy for Product Data Management interoperability within manufacturing process environment'. H. Panetto, M. Dassisti, A. Tursi.

Reference Information Model (RIM), which specifies the structure and expresses the discipline of data treated in a way that is suitable for each enterprise application. Due to that, issues may happen if companies use various repositories and avoid common methods to express the same data [21]. Moreover, they will need translation of those data that can cause loss and incompleteness of data. There are already regionally adopted (e.g. EU, USA) standards that can be utilised within enterprises, but there are still problems with syncing data within the scope of these standards as the existing ones require conceptualization and usage of diverse methods.

7.5 Backup management

All necessary files must be backed up on a regular basis, at least once a day, regardless of how the engineer or employer believes the PDM or IT systems are secure and it is always for a disaster event that might occur. For instance, corruption of files, viruses, HW/SW failures, or fires that might happen. According to estimations done, around 30% of CAD files become corrupted, lost, or damaged, and therefore a backup process is carried out to revert files.

But the issue is that there is no automated backup system in traditional PDM systems. Backup is usually quite expensive, time-consuming, and difficult; additionally, a specialised IT supporter must backup both discs that store CAD files and the SQL database that is used to track files [11].

Figure 18 Common errors that occur in PLM systems image from 'The state of product development & hardware design 2020''

7.6 Accessibility and Security

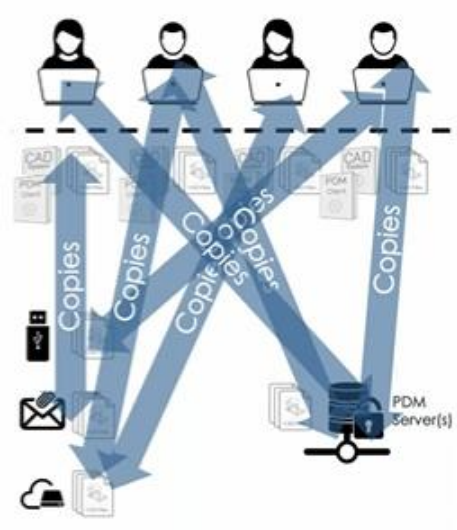

Figure 19 multiple copies that occur when there is exchange of data among PCs. https://www.onshape.com/en/resource-center/videos/solving-the-top-5-pdm-data-management-problems

Sometimes, partners strain the manufacturer's customer service organisations excessively through e-mail, phone, and fax inquiries. In traditional install-based PDM systems, there is an inverse relationship between how you access and how you secure data. There are always some trade-offs between accessibility and security with on-premise implementation and user-built web applications. There is no control or visibility of data once it is checked out. In a file-based world, it is also important to know where the file ends up being. Once it is checked out, due to the exchange of data, multiple copies (Figure 19) of files may appear and it leads to loss of essential data. The owner of data always looks after what is happening to the component design file after it has been checked out.

Furthermore, while exchanging files, workers at firms use email, and nowadays, many of those services use end-to-end encryption. However, when a file goes through email to an undesired receiver, the file is no more encrypted while the sender is unconscious if the recipient's security protocol matches the sender's [2] [11]. There is a probability that there is no password on the PC of the recipient or no firewall, whereas anyone can get a copy of the emails.

8. Operations with data

Usually, data is treated in various methods and goes through several processes. In this part, some challenges in data operations will be analysed to find solutions for upcoming issues.

8.1 Search/retrieval of information

Looking for and browsing data is an essential part of PLM systems. Kenneth McIntosh has stated that in firms operating in the production industry, planning engineers spend 15-40% of their working time carrying out usual routine searching and retrieving information. Sometimes, instead of wasting time searching for items, engineers prefer to create items directly by creating excessively equal components [2].

8.2 Exchange of information

In a daily manner, collaboration occasionally includes information exchange and transfer of information, and providing data about product changes, for instance, via a PLM system. E-mail, no controllable databanks on network drives, fax, and telephone are incompatible communication tools for well-governed cooperation in a heterogeneous environment [2].

8.3 Reuse of existing data

Because of the push principle in the distribution of information, in many product development systems, reusing the older product-related information or experience from functioning design solutions is challenging, which causes a lower quality of new products [2].

8.4 Uniform modes of action

The management of items, documents, and items' structure is linked to the dominating regimes of action of the company. However, the traditional performance of tasks is not always precise

and there is a need for exact instructions. Because sometimes instructions inside a group are managed approximately or roughly, whereas employees apply their own working methods. Therefore, it takes some time to modify dominant modes of action. According to Coopers & Lybrand, real value-adding engineering work makes up a very little part of the total time used in product development systems. About 20% of the time is spent on repeating tasks that have already been done before [2].

8.5 Data migration

Massively loading through data migration software such as Microsoft Excel and Access or other suitable programmes generally carries out feeding legacy information into the system. An additional challenge is that after carefully analysing relations between the separate assemblies and components, the preparation of this mass charging of the database usually requires a large amount of effort because diverse locations must be found for crucial information, which has to be made into a compatible form and gone through fully to ensure its validity [2].

9. Integration and connection of data with other systems

During the management of data within an enterprise, it would be necessary to integrate the data systems of different departments with each other. In this part, challenges regarding the integration and design of the PLM system with other product data systems will be discussed, and some possible obstacles will be outlined.

9.1 Direct Database integration

Database integration generally includes the usage of common databases. Specific information is shared between two or more applications. The data is replicated from one database to another when information is transferred. This method of transferring information is different from file integration, whereas database integration has speed and the ability to use a common database for many applications and data in one place. However, it has drawbacks, such as implementation can be quite heavy, making changes is more difficult, and it is quite costly [2].

9.2 Transfer file integration

Created information is moved/transferred either manually or automatically, and the exported file is read either manually or automatically by the application into which the data is imported. When there is file transfer among different systems, it is necessary to pay attention to exact agreements, classification, common terms and concepts, and the structure of the info. In practice, files are *.txt or *.csv types, and the general format for transferring data is XML (extensible markup technology) [2]. The disadvantages are that it is slow and does not operate in real-time. In addition, information must be replicated over several databases, and it creates multiple copies by making a mess.

The extreme issue in the management of old documents or items is moving all the old data to the new system or starting the use of the new system from a clean table.

9.3 Different methods for integration of system

As an enterprise management system, ERP (Enterprise Resource Planning) has evolved to handle large orders by coordinating all of the operations of the business (commercial, financial, purchasing, logistics, production, etc.). When PLM (Product Lifecycle Management) first emerged a decade ago, it helped accommodate many changes to organizational information systems. MES

(Manufacturing Execution System) was created for the purpose of regulating production operations in the manufacturing setting [3].

Systems that specialise in PDM include a lot of features and functions designed to manage documents and items. It is uncommon, for example, in ERP and CAD systems. In other words, many PLM systems do not include ERP system properties and they supplement each other. Current ERP and PLM systems are evolving separately, and there is a need for a unique and central IT infrastructure to support them.

Another objective is that data should always be updated in one place. Other systems should be able to read directly from those PLM systems and not all systems can carry out that.

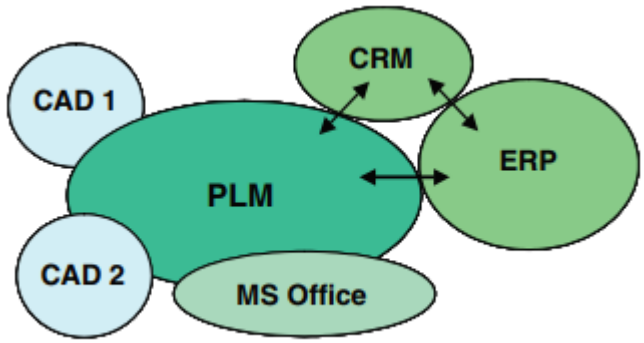

Figure 20 Integration of PLM with other systems. Image from 'Product Lifecycle Management - A. Saaksvuori, A. Immonen'

When designing the relationship between PLM and other systems, other systems should be taken into consideration.

1. Enterprise resource planning (ERP)
2. electronic or mechanical CAD systems.
3. Customer relationship management (CRM) or other sales systems.
4. Bookkeeping, accounting, other design (image editor), e-mail, net browsers, reporting applications.

During integration, there may already be systems in use that could have been substituted with some other system used in the company. The features of new systems have perhaps not been used to their maximum possible extent. Long-lasting infrastructure planning is frequently complicated by the fact that the project targets must be achieved within tight schedules. Furthermore, there may not be enough skilled labour, and only a few experts may be able to participate in every development project [2].

9.3.1 Integration of design and ERP systems

As stated earlier, each department of the company has its own system. There are different in-house CAD systems in engineering and ERP, which is responsible for material management. Usually, the transfer of product information is performed only among separate CAD systems [11]. Common methodologies in data transfer among distinct systems involve many shortcomings, which cause the generation of overlapping product data and several manual reworkings.

9.3.2 Accessibility by ERP system

Generally, subcontractor connection to the information processing system of the enterprise is provided by ERP and PLM systems, either directly or indirectly, with distinct e-business applications. In some cases, the supplier does a final inspection of delivered components, and the client also does similar inspection activity after delivery. Information asymmetry between parties causes the creation of extra steps and loss of time. There is no need to perform the same task again [11] [15].

9.4 Old integration methods

The old and widespread way of integrating mainly is point-to-point (Figure 21), whereas product development systems are linked to other systems separately by creating excessive connections and inefficiency. Even though there are strong links between each system, maintenance of those relationships is quite laborious [2]. Moreover, when an application that connects each system needs an update, maintenance, or reinstallation, it will become expensive for the firm itself.

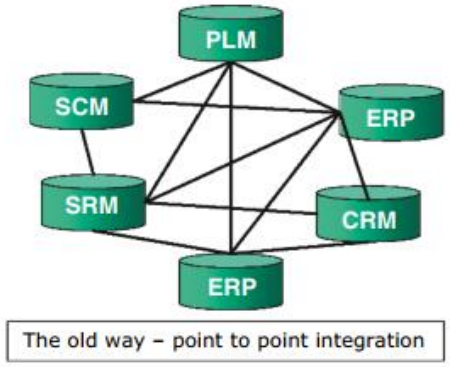

Figure 21 Point to point integration. Image from 'Product Lifecycle Management - A. Saaksvuori, A. Immonen'

9.5 Integration of PLM with ERP and MES

Long-term product quality is ensured by integrating ERP, MES, and PLM modules together. To establish a feedback information technology that can cover the manufacturing process performance and increase the quality of made products, these two entities must be integrated.

When the PLM system was still in its infancy, the ISA 95[1] focused on horizontal collaboration from ERP to manufacturing. Every bit of product-related data required for production management, such as Bills of Material, Production Scheduling, and Planning and Control, was captured in the ERP system according to these standards. Additional data included work instructions, operations, machine availability, and production personnel in the MES relevant to the items in question. Deploying PLM solutions today puts these options to the test and forces businesses to re-examine their use of information systems. However, SMEs face significant challenges due to the time and expense involved in implementing these information systems (Small Medium Enterprise).

Since we've covered so much about how information systems operate, the biggest difficulty for businesses is acquiring these systems and getting product data flowing across them. These information systems are not available to all industrial organizations, and varied storage methods expose a lack of data management and process control in the unavailability of these systems. Due to this restriction on the use of various information flow technologies, data updates are postponed and incomplete data is communicated to manufacturing. As a result, it becomes critical to examine the relationship between manufacturing execution systems (MES), product lifecycle management (PLM), and enterprise resource planning (ERP) in order to meet all these problems.

10. Analytics within Enterprise

In the usual sense, firms always need analytics and real-time data for effective management and defining their strategies and acting within competitive markets. Therefore, some discussion is

[1]For building an automated interface between business and control systems, the International Society of Automation has established an international standard known as ISA-95. International producers helped design this standard.

carried out in order to outline some crucial data that is necessary for the effective management of an enterprise.

10.1 Analysis controlling business process

The ability to get and use real-time or past period data with clear indicators and metrics plays a significant role in business performance. For example, there may be a need to get actual and analytical information with graphs and correct diagrams about ongoing projects and the overall enterprise situation for a predefined period. The issue is that necessary information is scattered among different departments and work organisations [11]. Even if it is possible to get data about the current situation, retrieval of such information might take longer than anticipated, delaying project management and informed lifecycle decision processes. Company managers always require good info, functioning metrics, exact figures and diagrams on which to base their decisions.

10.2 Analysis of whole activity through unique software

The newest and most important report always remains expensive. It is rare to find a fresh report about the current product development process directly from CAD, and this makes it difficult to evaluate the effort of each workforce member or analyse key performance indicators connected to the entire design process. Furthermore, managers of product developers have no way of controlling what their design teams, or even contractors and vendors, are doing in real-time. Most of the PLM systems that control product development systems do not hold clear and live analytical tools to acquire definite statistics on firm processes. Statistical analysis is needed to diagnose the current conditions of firm operations and position [11] [22] [21]. For example, how projects are progressing (duration, cost, and plans), how many employees are in the company and what they do, how suppliers and customers are linked to the entire system and identification of employers who are putting forth effort in work for an award and other firm-related statistics.

10.3 Importance of data for decision making

The biggest problematic field in this context is usually the incapability of the management to make informed lifecycle decisions. It means that firm executive managers do not have sufficient and current information, functioning metrics, processes, and a clear frame on which to base their decisions. In addition, management needs to know the current condition of the firm's projects and the expected maturity of the product in order to kill it at the end of the 5^{th} phase, according to information that was retrieved by analytical tools. Overall, with current inefficient PLM and CAD systems, decisions are hard to make for efficient management [2] [6].

10.4 Traceability of errors or owners of works

Moreover, there is difficulty in finding who did that mistake. One of the causes is the lack of traceability in change management and design history [11]. Not all product design software allows for worker tracking or approval of the person responsible for the errors. Traceability

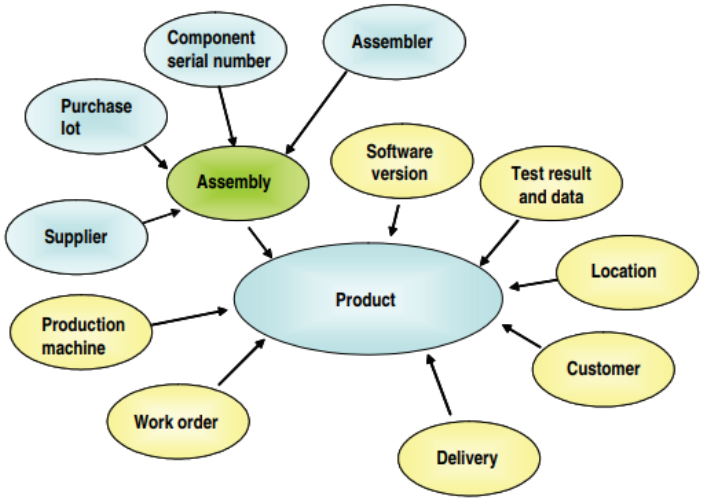

Figure 22 Data linked to the traceability of the specific product. Image from 'Product Lifecycle Management - A. Saaksvuori, A. Immonen'

should not exist only for product design, but it should be included during the order delivery process, which includes procurement, production, and delivery processes. It is currently problematic due to current IT systems and only few companies make investments in the development of that IT infrastructure. Commonly a large amount of traceability data linked to a specific product and its production, testing procedures are mobilised during the production [2]. However, the information is usually kept inside one company or inside a specific production unit on distinctive info-processing systems.

Still, in many companies, there are separate information systems for procurement, production, maintenance, but each system manages only its own small stake in the jigsaw puzzle. The biggest problem is not just collecting data, but the capability to link all the information gathered on the islands of systems [21] [22].

10.5 Version history

During design processes, engineers may create multiple versions of one component, and management of those versions within PDM can be time-consuming and effort-taking. Versions of components can be saved in separate folders by making them difficult to retrieve when needed [11]. In addition, 8 out of 10 designers and engineers come across issues in finding the right version of their component designs and have issues accessing their data [8]. Old PDM systems in PLM do not allow clear visualisation of versions and maximum efficient usage of CAD platforms for effective version usage without any problems.

11. Impact of the design process and CAD on PDM

During direct product development processes such as design, engineers always confront challenges in product data management, and CAD applications are directly dependent on PDM. Hence, in the following sections, some issues related to those problems will be discussed to tackle them in the future.

11.1 Difficulty in Collaboration with CAD

Even though many CAD sellers claim their marketing activities are centred around collaboration, CAD applications were never created with collaboration in mind. The basic issue interrupting efficient collaboration with CAD data is that only one person can edit a drawing document or file at the same time. Engineers usually make copies and make changes to the files in order not to affect negatively the previous work by another designer. Overall, it avoids the main destiny of collaboration, whereas each worker is carrying out his stuff on distinct copies of diverse files [7] [15].

11.2 Concurrent engineering with subcontractors and their access

When there is a need for a change in product features and design, it is difficult to manage modifications with current product development systems. One of the reasons is that sub-contractors are not able to utilise the principles of concurrent engineering within the PLM systems of their partners. Moreover, if a subcontractor needs to access the databanks of the firm, they need to pass over overlapping work, and there is no clear framework and fast way to access them by considering the security of the databanks [11]. So, the synergic advantages of the integrated use of systems are not fully utilized.

When acting simultaneously with concurrent engineering (CE) principles, in a short period of time, huge amounts of information are produced and other teams, departments, or companies ought to be able to use that data [2]. It is problematic with current design software and production systems, whereas each system could use each other's information. At the same moment, the importance of physical distance should be removed.

11.3 Typical issues during Collaboration with internal teams due to poor PDM

11.3.1 Conflicts

If many individuals even work on a copy of the file in the same file at the same time, one or more of the people will be extremely likely to make modifications to cause a design dispute. Although the disagreement might have a dominant impact on other sections of the project, on other components of the design or design concepts. These disputes are tough to solve and involve several discussions and design revisions, if not impossible [11].

11.3.2 File corruption

If a designer has more than one programme in order to write to the same file, there would be conflicts of data structure that could not be addressed, and the likelihood of a file being corrupted is great. Whenever a file is broken, both the CAD and the operating system cannot read the proper data and cannot deflect any defective data structures. The file is classified as defective and useless [11].

11.3.3 Lost work

There is a "last save wins" game when more than one programme has the same open file for modifying simultaneously. The time Engineer 1 devoted to altering a component or assembly carefully will be lost as someone else has saved his work after Engineer 1 has stored his, modifying it at the same time. When he opens the file, it appears entirely different, and everything he did is eternally gone [11].

11.4 Engineering change orders (ECOs)

Change orders (ECOs) for engineering projects are not really a wonder to engineering designers. Design improvements are often needed, whether they are design advancements or modifications needed for production. No design is flawless the first time around. ECOs are often undertaken after a product has been launched for production after issues detected throughout this initial project have been resolved as a result of the normal design stages. Right now, all ECOs are thoroughly scrutinised in design reviews to make sure they're worthwhile. An ECO is essentially a reworked version of the original design. Whenever one part of a product is altered, it almost always has an impact on other parts of the product as well. As users pursue interconnections and tolerance stack-ups around a design, the labour necessary to implement an ECO may grow tenfold when using PDM systems to manage all the information. Workflows often control the ECO process by allocating rights and informing participants who subsequently check out the files to perform the requisite modifications [11] [6].

That is an undeniable fact within the product development system, whereas users are required to check files in and out for change – and the system allows only one user at a time to open and edit a design file. Because one design file often references many others (e.g. a big assembly), this can mean locking up many files at once. The consequence is a serial workflow, in which most engineers are required to pause for co-workers to accomplish their tasks before they can continue with their own [16]. Following fixed protocols and regulations is a safeguard against mistakenly working on the wrong version, but it also creates unnecessary downtime. Forgetting to check the files back in leads to major headaches.

Moreover, after modifications, some issues may occur among engineers. In other words, the product data concerning component items is not current and is not reliable. Most of the time, it is hard for product designers to define which design is the latest or not changed yet without any other versions of components. Furthermore, nonregistered modifications cause conflicts among stakeholders, such as the manufacturing of erroneous products in the market if there are no automatic notifications to inform them or asynchronous updates of design models for production [11].

PART III: MANAGEMENT METHODS WITH CLOUD-BASED PLATFORMS.

12. Cloud Applications in Enterprises and Main definitions

Today’s firms are moving towards cloud programmes and solutions with clear long-term perspective strategies for gaining competitive value, but not with short-term intentions. This gives advantages such as quicker innovation, more flexibility, more exchangeability of software providers with all-tech inclusive subscription, more concentration on the users, less tech dependency with cheaper prices [23]. However, the issue related to that is the integration of diverse cloud technologies with on-premise backend solutions, which must be managed with good technological experience and knowledge.

12.1 The cloud landscape

The cloud environment is vast, diverse, and complicated. The U.S. National Institute of Standards and Technology provided five important features of cloud-computing and they are:

Figure 23 Bessemer Venture Partner's picture of the top 300 cloud companies in 2012

Broad network access, rapid elasticity or extensibility, resource pooling, measured service, and self-service on-demand [24]. Nowadays, multiple companies utilise the capabilities of cloud computing from low-level simple computing and storage to complex integrated software to increase efficiency in the company. Service is also strongly influencing engineering companies, whereas data management is a crucial lever in managing the repositories of an organization. Now, let's see the following definitions of the abovementioned features of the cloud in order to get an idea of how it works.

- On-demand self-service - A consumer is free to supply computational capabilities, such as time for the server and network storage, unilaterally when necessary, without any human involvement.
- Broad network access - Capabilities can be accessible through the network through standard procedures that support the use of heterogeneous thin or thick customer platforms (for instance, mobile telephones, tablets, computer systems). As mentioned above, some CAD software, which was developed earlier, is not capable of holding those features.
- Resource pooling - The computer resources for the provider are combined to serve several clients utilising a multi-tenant architecture that dynamically allocates and reallocates distinct physical and virtual resources to meet the consumer demands. There's a sense of location independence because the client usually does not have control or information over the accurate location of the supplied resources (e.g., country, state, or datacentre). For example, storage, processing, memory and network bandwidth are resources.

- Rapid elasticity - In some situations, the ability to quickly scale outwards and inwards according to demand can be elastically provided and removed. The consumer typically has an infinite capacity to supply and may be appropriated in any quantity at any moment.
- Measured service - By using the metering (pay per use) capabilities at certain abstraction levels that are relevant to the kind of service (for example, storage, processing, bandwidth, and active user accounts), cloud systems regulate and optimise resource consumption automatically. The use of resources, both by the service provider and the consumer, may be monitored, regulated, and reported, which may seem transparent to clients [25].

12.2 Service models of Cloud

There are three main service models for cloud technology, each of which caters to a particular set of corporate needs. Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS) is the three paradigms mentioned above.

- Software as Service (SaaS). The ability of the consumer to utilise the provider's cloud-based apps is limited. The apps can be accessed via a thin client interface, such as a web browser (e.g. web-based e-mail) or a programme interface, via various client devices. With the potential exception of restricted application configuration, the customer does not manage or manage the cloud infrastructure, including network, servers, operating systems, storage or even individual app settings.
- Platform as Service (PaaS). Consumers' capacity to deploy consumer-made or bought apps on cloud infrastructure was built by utilising provider-supported programming languages, libraries, services, and tools. The user doesn't control or manage the underlying cloud infrastructure, including network, servers, operating systems, or storage, but controls the apps installed and possible setup parameters for the app hosting environment.
- Infrastructure as a Service (IaaS). The user has the power to supply processing, storing, networking, and other basic computing resources so that they may deploy and execute any software, including operating systems and other software. It's the client's responsibility to monitor and handle the operating systems, storage, and programmes that are used in the cloud. The user may have restricted control over some networking components (e.g., host firewalls) [25].

12.3 Deployment models for Cloud

There are four types of cloud deployment: private, public, community, and hybrid. Every model of deployment has a specific definition based on the location of the infrastructure required to support it.

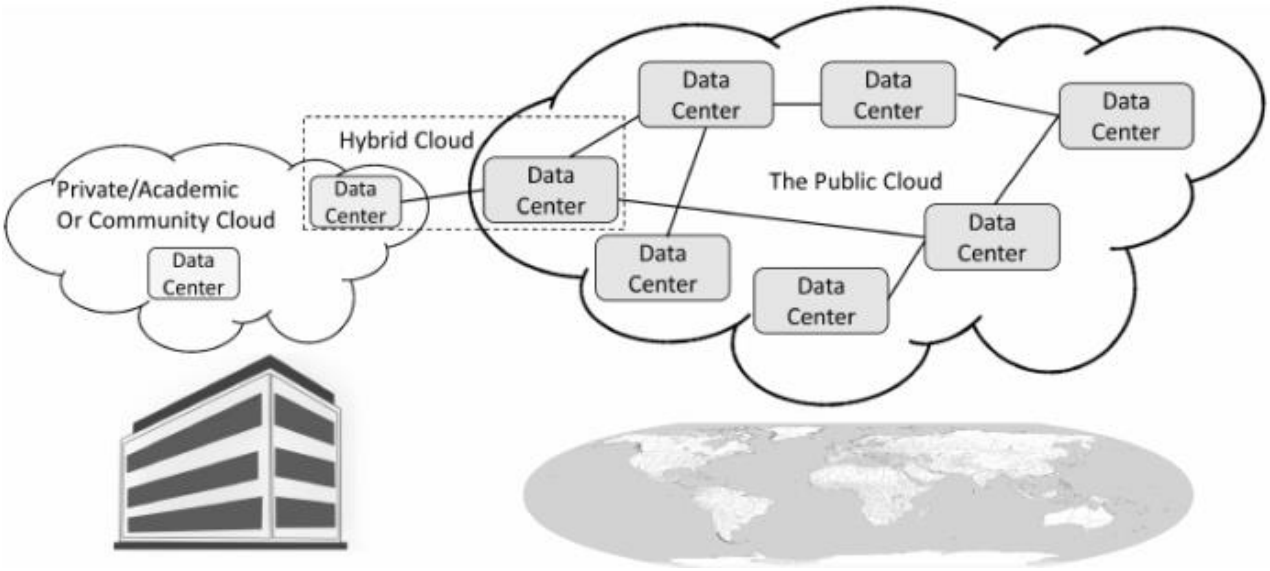

Figure 24 Distinct cloud providers image from 'Orienting in the cloud universe' by Carlin George

Private cloud. A single company comprising several consumers provides cloud infrastructure for exclusive use (e.g., business units). The organization, a third party or a combination of it can be possessed, managed and operated and exists on or off-premises.

Community cloud. A specific community of consumers of organisations with common concerns (e.g. mission, security requirements, and policy and compliance issues) provides the cloud infrastructure for their exclusive use. The organisation may be owned, managed and operated by, or combined by, one or more of the community organizations, a third party or on- or off-site.

Public cloud. The public cloud is provided with cloud infrastructure for open use. It can be owned, operated, and managed by a company, an academic institution, or a government agency. It exists at the cloud provider's premises.

Hybrid Cloud. The cloud infrastructure is a composition of two or more separate, private, community, or public cloud infrastructures that remain unaccompanied, but are linked by standardised or proprietary data and application portability technologies (e.g., cloud bursting for load-balancing between clouds) [26].

13. Why SaaS? (Cloud-native vs Cloud-enabled)

Almost all *cloud-native* software provides one common beneficial commonality, and it is a single source of correctness. This remark considers how data is stored, processed, and entered by those who demand it. When there is only one version of the data, so everyone can see the same file simultaneously wherever they are. These have an incalculable number of positive effects on communication and collaboration while also reducing errors and rework. All these are provided by a single SaaS application.

Oppositely, *cloud-enabled* software (must not be confused with cloud-native) is a class of computer applications with a cloud repository capability. This means that replication of the data

is kept and processed locally. Hence, it can be out of sync with the master duplication in the cloud [4]. Diverse workers might recognise distinct versions of the same file. Rather than contributing to a limitless repository and automated backups, this manner of delivery completely undermines the purpose of the cloud and should be avoided at all costs [16].

13.1 Four common benefits of SaaS tools

Besides all the advantages of product design teams, project managers and engineering managers, SaaS platforms are particularly beneficial for the CIO and its IT teams. Many organisations are pushed by the cloud-first strategy of their CIOs to optimise corporate processes, enhance the productivity of employees, save costs, and ensure the company is competitive [16]. Organizations, especially IT teams, can economize a considerable amount of time and financial resources if we transfer as many business operations to the cloud.

13.1.1 Scalability

With organisations growing, they are also more in need of additional workers, contractors, and software solutions. SaaS provides quick deployment with fast supply and de-supply of users from a central administration dashboard by the nature of not needing to install the software. Compared to hours or days, new users may work with solutions on-site and run within minutes. This allows project managers to swiftly re-allocate engineering personnel to ensure the completion of projects promptly. Users may be de-funded in seconds and their access to corporate data can be immediately reversed when the contractors' term has expired or a project is concluded. The cloud's elasticity allows SaaS providers to assign more computation and storage capacity, based on international demand [16]. Additional resources may be added when the workload increases and more users add up. Everything is automatically taken care of [27]. IT staff should not have to worry about operating and maintaining their own servers, networks and storing systems with "infinite" storing and computing power.

13.1.2 Security

The security of commercial cloud providers is first-rate. As a result, integrating cloud services into a business network is a simplicity [27]. It is a potential danger to security to send sensitive material over e-mail or any other channel. This includes laptops or remote computers used by employees to download data to work. There is no way to determine where or who has this data transferred beyond the business firewall. An unknown number of uncontrolled copies can be placed in unknown locations on servers and computer hard disks. This may be permissible, but cannot be assured if such places are known to be in a trustworthy network. Unregulated copies may also lead to erroneous versions of the data being used to decide on businesses or produce components for millions of dollars each year.

SaaS supplies the software programme and related cloud data. No data will be sent or downloaded to a user's machine locally. Every action of data processing takes place remotely and the results are shown on the device of the end-user. In fact, no data is sent even while exchanging design data with others. This ensures that critical IP is always secure. Strong cryptographic cypher suites, encrypted storage, one sign-on (SSO), two-factor (2FA), or other security features can all work for SaaS services beyond what most organisations can (or offer themselves) [4].

13.1.3 Profitability

With the SaaS delivery paradigm, numerous IT overheads are removed. Equipment, such as workstations, dedicated servers (installing and maintaining adequate cooling, fire protection, and physical safeguards in server rooms), network infrastructure, firewalls, VPNs, storage, back-ups, and recovery plans for disasters, are no longer required and utilities are significantly reduced. Maintenance of software such as downloads, installs, upgrades, service packs, licencing codes and all troubleshoots and downtime related to such activity is a thing of the past.

SaaS licences are built on a yearly subscription model that shifts costs from high capital costs to small operational costs, reduces overall ownership costs and reduces financial risk. This releases IT funding for other expenditures and enhances visibility and strategic planning [16].

13.1.4 Reliability

Cloud reliability is frequently a worry since a failure might result in major software and services being inaccessible and a business being unable to function while this critical service is offline. Conversion SaaS systems are designed to resist system failures caused by desktop applications, which can crash or lose or corrupt data. Data is stored and copied automatically across many areas and redundant servers are ready for substitution in the event of a breakdown. In many cases, a user will not even realise a problem has occurred, and failover systems will solve the problem in milliseconds [16].

13.2 Accessibility through other devices.

A researcher at a small college or a small firm engineer may not even own a computer room or laboratory with space for machine racks. The only option is the cloud. It is possible to use a Web browser on any computer or a specialised mobile app on a smartphone or tablet to access the cloud-native application [27]. This guarantees access to data from all places with an internet connection and from any device available. This facilitates access to data not only in regular places of work but also while the user is at a customer's site, in a cab or at the airport. Sales may offer customers the newest product line updates, managers can sign up for important design choices, and on-the-fly adjustments can be made by engineers as and when necessary [16]. All data is live so that everyone is instantly alerted of any changes.

13.3 IT outsourcing

IT departments play essential roles in a firm with the alignment of business strategies and IT technologies for greater success in the market. As discussed above, it is quite costly sometimes to manage and exploit the IT part of an enterprise, and it is laborious [28]. For that purpose, cloud applications do not require specific IT departments and labour for effective management, whereas they can be outsourced externally by economising financially [20]. So, enterprises can avoid managing IT stuff internally and employing specialised staff for that purpose.

14. Security management within Cloud

Even though cloud solutions offer flexibility and cost-saving, security of sensitive data and privacy remain crucial and customers try to avoid cloud outsourcing [29]. But there are specific encryption methods that address specific issues, such as Pailler's homomorphic encryption, Identity-based encryption, Role-based encryption, Attribute-based encryption [30], TLSv1.2, or other ways that disable security problems. However, according to Naidu [31], encryption necessitates the use of a role policy technique to address the issue. This policy access is an access policy that contributes access to users based on their features.

14.1 Data integration security and Confidentiality

Due to the complexity of cloud solutions, they are usually difficult to implement and time-consuming to maintain. While integrating, attacks on the system can be conducted, and some security solution is needed for this. For this purpose, role-based access control is used to cope with confidentiality and data integrity issues. Role-based control puts limits and permissions, and access is based on the needs of the group in the firm. Hence, it reduces the risk of data breaches and decreases third party dangers. Current cloud-based software is based on role-based access control, which secures data confidentially [30] [31].

14.2 Lack of visibility and control

If the organisation utilises cloud solutions and its resources are located outside the organization's network circle, the agency loses complete control over its resources and may overlook some dangerous attacks due to an incorrect sense of security. In particular, if servers are located outside the organization's building and there is no responsible authorised person from the organisation monitoring data centres, it might cause loss or potential attacks by hackers or lack of qualitative data treatment [30].

15. Cloud-based PLM/PDM in Organizations

Almost half of the respondents within Enterprises use an add-on PDM/PLM. In comparison with those employing cloud-based data management, two times as many PDM/PLM customers are using installed server-based systems. (In all categories, respondents were permitted to reply in both categories.) In this section, the general implementation of cloud-based platforms and SaaS

service models within the engineering industry or product development will be discussed for deep analysis (Figure 25).

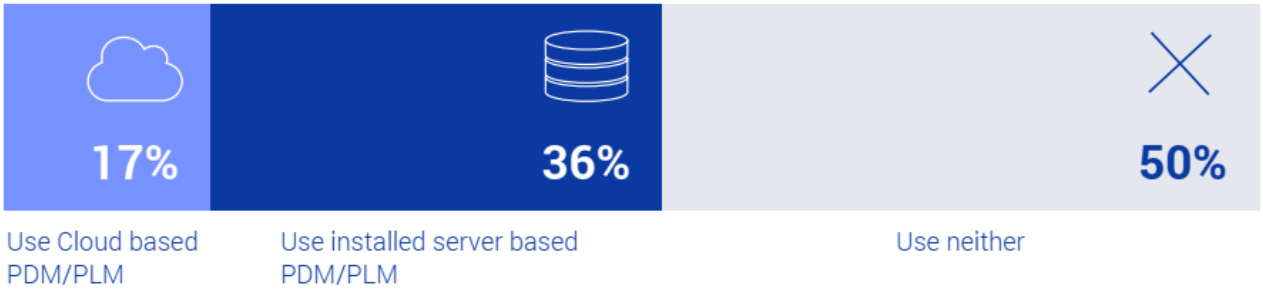

Figure 25 Product development team usage of PDM/PLM systems (2020) image from statistics form 'The state of product development and hardware design 2020'

15.1 Communication and Collaboration within the cloud

Google Suite and Microsoft Office 365 tools are common in offices to increase efficiency in an organization. However, it is undeniable that cloud-based productivity tools are being used in the workplace to make it easier to share files and collaborate in real-time with a large number of colleagues and partners [20].

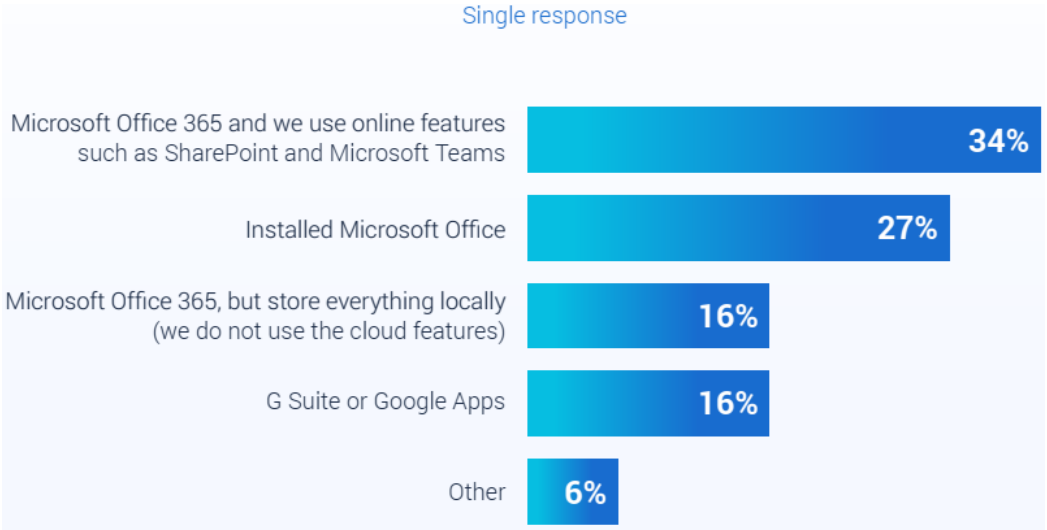

Figure 26 Office productivity tools used most. Data from 'The State of Product Development & Hardware Design 2019'

Multiple contributors are capable of working without considerable effort on the same documents, spreadsheets, or presentations online. Instead of emailing static files back and forth with names like 'A1, A2, A3, etc.,' co-workers can create, edit, revise, or contribute feedback in a unique central repository in the cloud – returning to any stage of a document's history to track modifications (or even restoring a liked version of the file). Considering survey respondents about the usage of SaaS tools (Figure 27 [11]), it is clear that 69% of organisations participating in the questionnaire indicate that they are operating on at least one Software-as-a-Service (SaaS) cloud-based productivity tool. As mentioned above, it is purchased by subscription. True SaaS is web-based on-demand software that does not require downloads, maintenance, or installations. Whenever the workers sign in, every user is automatically on the same version of the software.

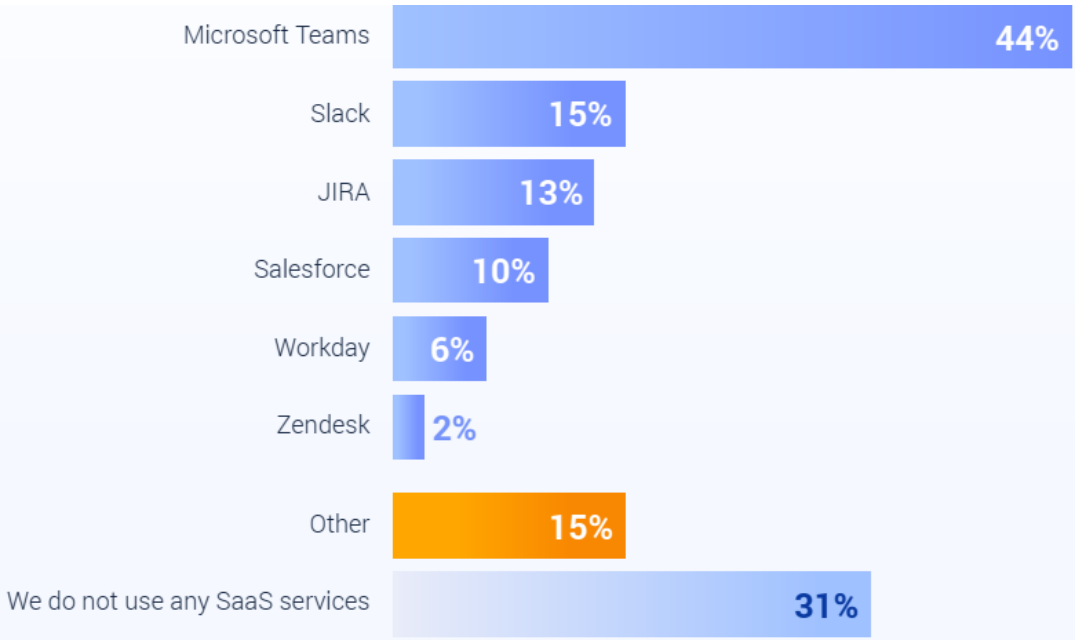

Figure 27 Use of SaaS tools. Data from 'The State of product development and hardware design 2020'

15.2 Possibility of Implementation of Concurrent engineering in Cloud

The cloud also stimulates teams to make early and frequent modifications to product design data, especially in initial development stages in which design change costs are small. Consequently, this reduces cost, time and improves product quality overall. Everyone works in parallel. The age-old notion of concurrent engineering (CE) aims at early identifying and resolving problems. It provides more innovative ideas since more individuals together have the chance to discover, examine and solve a particular problem. Teams typically have various skills, and their

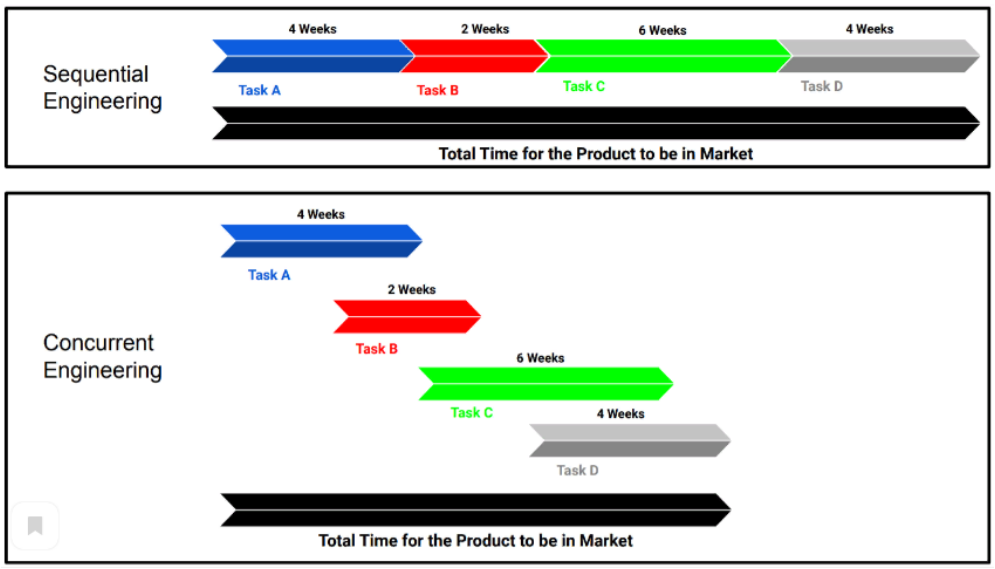

Figure 28 Workflow for Simultaneous and Sequential engineering image from https://www.smlease.com/entries/product-design/what-is-concurrent-engineering/

combined expertise may be leveraged to a great advantage if they can all contribute to the lifecycle of product development. It includes a certain amount of redundancy and decreased risk with additional team members participating in every stage of design when team members are sick or on vacation. Cloud-native applications interconnect teams inherently, and everybody

sees, in real-time, what everyone else is working on so that everyone can offer feedback and advice for a genuine concurrent engineering experience. This involves interacting with suppliers, contractors and manufacturing partners outside your company. Through the early engagement of partners with domain expertise, issues that usually occur later during fabrication may be detected immediately, therefore helping to save costs [16] [15].

15.3 Work from home

Recently, the effect of Covid-19 has had a major impact on the employees of large and medium companies who used to commute to work locations [32]. However, remember that the recent

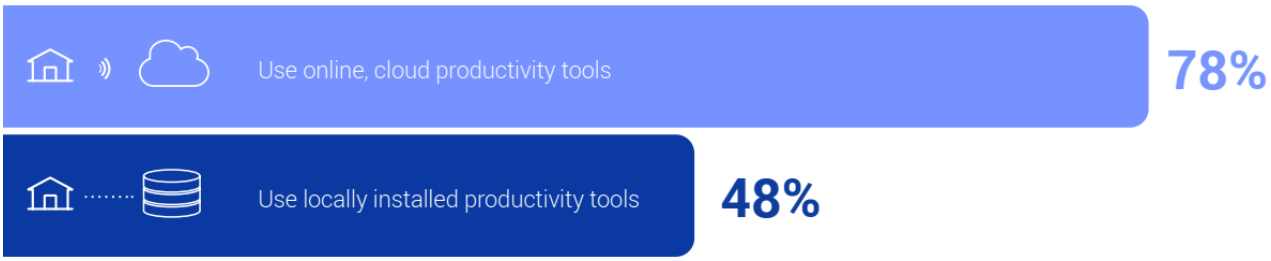

Figure 29 Percentage who rate their ability to support remote workers statistics form 'The state of product development and hardware design 2020'

popularity of cloud applications such as Zoom, Microsoft Teams, and others can be a good example of what communication and collaboration would be like without the internet. Eight of ten companies that utilise cloud-based productivity tools are convinced they are prepared to help their teams irrespective of where they are carrying out working activity from [8].

How are organisations prepared to accommodate a remote workforce after being taken off guard in 2020? Product development specialists across the board, who assess their firms as having "excellent" productivity, are far more enthusiastic about their team's move to home offices when they are wanted or require it.

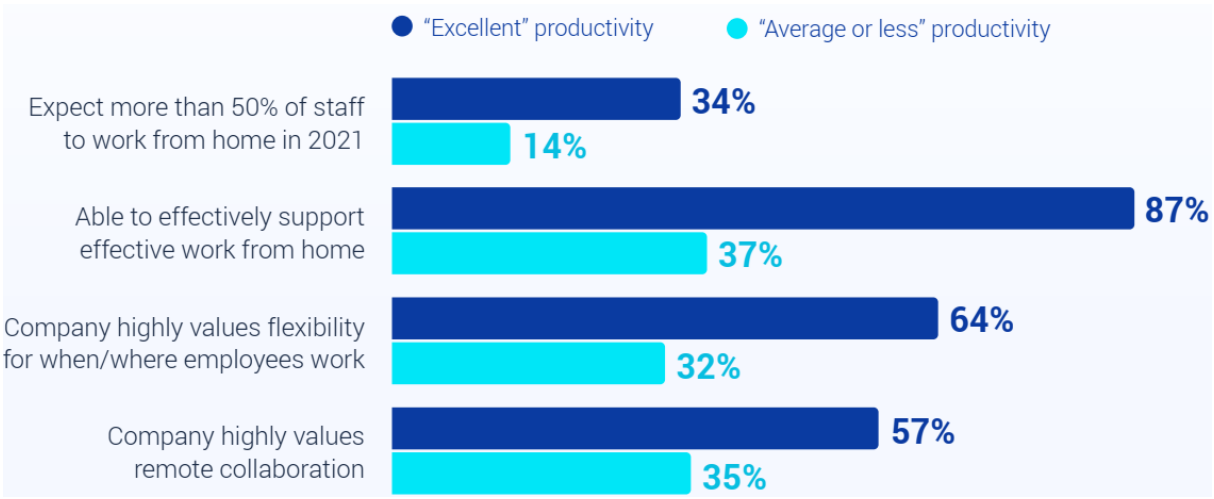

Figure 30 WORK-FROM-HOME Anticipation and Capabilities comparison of high and low productivity firms. Image from 'The state of product development and hardware design 2020'.

15.4 Agile project management for cloud-based SaaS products

Today, many software developers are implementing *agile* project management methodologies in order to satisfy currently unstable and changing market demand. The *agile* approach to project

management facilitates the creation of complicated systems progressively/iteratively. There are some frameworks of implementation of this approach in product development, such as Rolling-wave planning, Loose-tight planning, Time-boxing, Scrum etc. [6] Each framework has its own scope and implementation purpose, but Scrum is the most widespread among them, which is gaining popularity in the technical industry. According to Puneet Agarwal [14], the utilisation of Scrum with a rapid release cycle for SaaS infrastructure cloud-native tools enables product developers to create new features and version upgrades very quickly and qualitatively. Therefore, both ideally suit each other for managing SaaS products. So, what is the Scrum Agile Framework?

Scrum contains empowered teams with self-organized meetings every two or four weeks and "sprints" with clear objectives, daily stand-up meetings, and persistent monitoring of backlog/progress. The objective of the Sprint Plan Meeting is to agree on the sprint targets and to discuss the elements of the Sprint Backlog PBI (product backlog item). The Sprint Backlog is a sprint for a team to fulfil user stories. The Scrum Master is the lead, coaching, teaching, and supporting role of a Scrum team and their surroundings to ensure that Scrum is well understood and used [33].

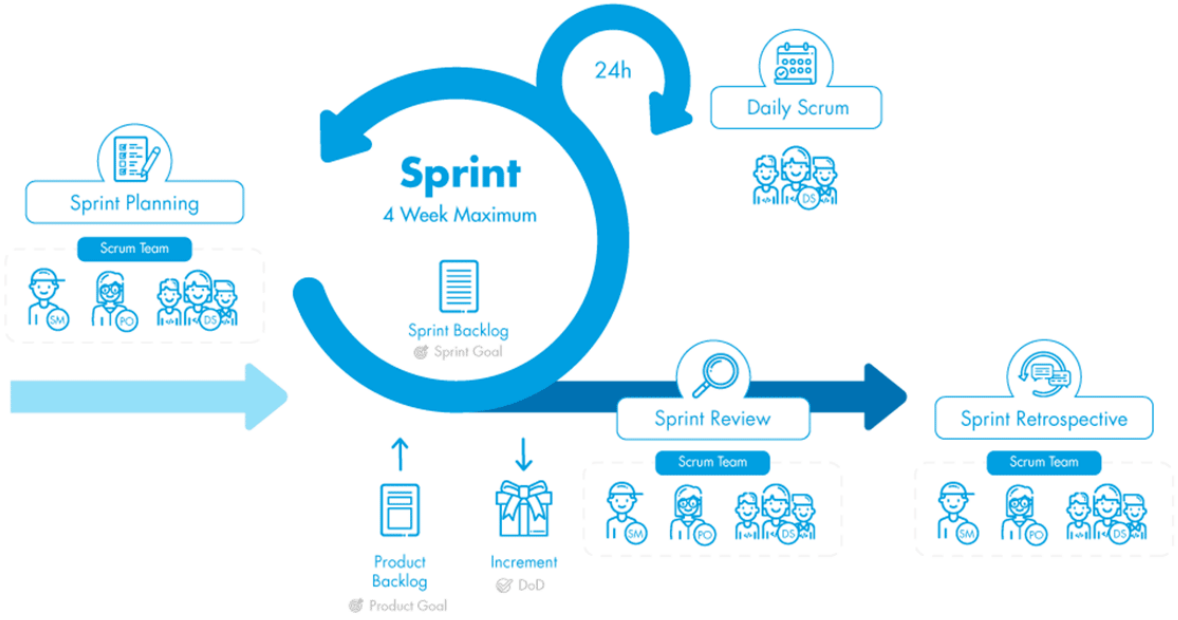

Figure 31 Typical Scrum framework infrastructure image from https://netmind.net/en/the-past-present-and-future-of-scrum/

This is just a specific framework that can be implemented for easy management of SaaS cloud-native tools, although as mentioned above, there are other agile project management frameworks for implementation.

15.5 Fully Cloud-based CAD applications

Analysts have recently found that, in a research study by the Aberdeen Group, 231 organizations, the numerously major enterprises and small enterprises that utilise Agile Methodology to speed up their development processes may easily choose from the various benefits of cloud-based CADs. The research finds that companies using cloud productivity tools can easily cooperate, remain nimble, and have real-time insight throughout their operations. In this way, firms may

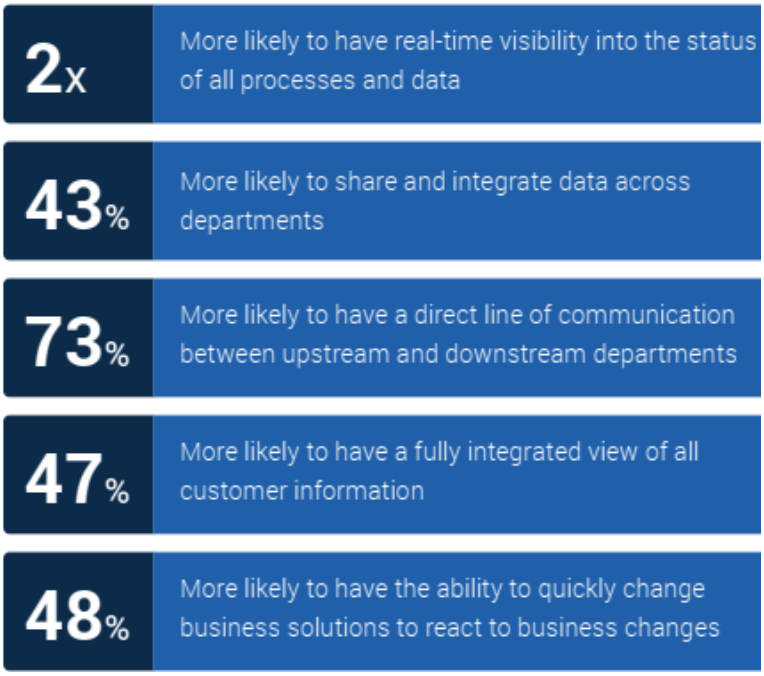

Figure 32 Properties of Companies using Cloud-based CAD solutions in comparison with traditional CAD users. Statistics from 'The Ease of Agile Development in Cloud-based CAD, December 2016, Aberdeen group.'

distinguish themselves from their rivals by producing excellent, timely items [7]. Autodesk Fusion 360 and Onshape are two contemporary and well-known cloud-based CAD programs on the market. First and foremost, Autodesk Fusion 360 is a cloud-based CAD application from the Autodesk suite (which also embraces AutoCAD, 3D Studio Max, and Alias). It has surface and solid modelling software products for commercial and mechanical design. The program may be used on a variety of devices, including PCs, Macs, and smartphones. Fusion 360's dashboard platform is similar to GrabCAD's toolbox in that it allows teammates to keep track of design and task modifications in the cloud. The fact that models and graphical representations are enabled by browsers, allowing for viewing on any device, is one of the many advantages of owning CAD embedded in the cloud. This is sufficient for face-to-face meetings, but it does not allow for worldwide cooperation, which would necessitate the use of Skype. The Autodesk Fusion 360 CAD interface design is similar to a direct modelling method, with a focus on quick updating and model generation. Onshape has a modest number of industrial clients, but its potential in research has yet to be noticed [34].

PART IV: Exploratory study of cloud-based PLM platforms

16. Onshape Cloud-based engineering tools

Onshape is a CAD software system supplied over the Internet through a service software model (SaaS) software. It makes heavy use of cloud computing, computational processing and rendering on Internet servers, and users can use an Internet browser or the Android & iOS apps to access the system. Further details and its features will be discussed in more detail in order to give proper specific and objective solutions

Figure 33 Firm's and app's logo with possible usage gadgets differently from traditional CAD apps. Image from https://www.ttprj.com/

to the problems mentioned in the first and second chapters. However, since Onshape's main product is the Onshape cloud-based CAD application, extensive analysis of the company's other integrated Cloud-based PLM tools will be done for the achievement of a know-how solution to PLM issues. However, for the time being, some of the main capabilities of the Onshape CAD application will be discussed and analysed in order to provide solutions to the issues mentioned in product development processes and PLM systems.

With cloud-based CAD software, 3D part and assembly modelling may be done entirely in a browser window. Rather than paying for an expensive, node-locked yearly license or infrastructure-heavy floating license, these solutions are delivered as SaaS. Individual users, consultancies, and Makerspace/Fablab providers will appreciate this configuration, and it might also have significance for academic and student use [34].

16.1 Possibility of creating an international team.

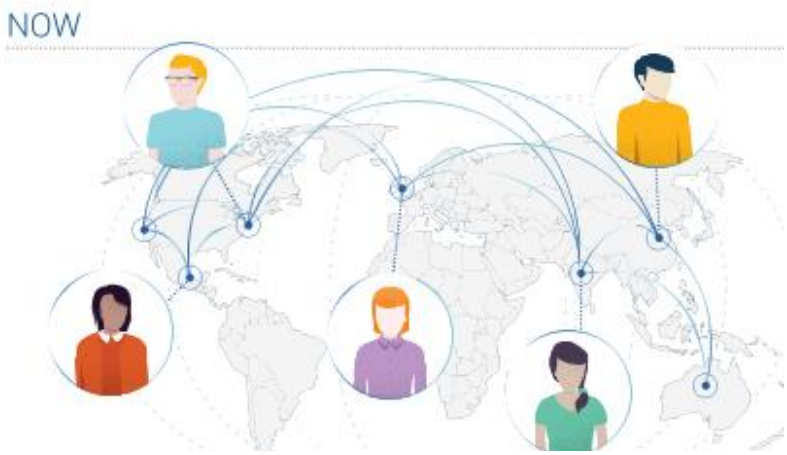

Figure 34 It is possible to compose team internationally. Image from 'Introduction to Agile product design, W. Need'

As mentioned above, traditional CAD applications permit team work only in one building under one roof, which limits companies' recruiters' ability to employ skilled workers from all over the world. For this purpose, Onshape allows easy team composition by just adding new employees with little effort and a few clicks [7]. According to Marco Cantamessa [6], decentralised R&D and product development centres allow access to knowledge residing abroad, and it is beneficial to be close to market and development activities, while outsourcing gives the advantage of cost savings because of low salaries in diverse countries.

Adding and eliminating team members. In detail, the email of a new worker is sufficient to add a new team member to a project or functional team. Because of new licensing, installing new applications, and additional cost problems, Onshape created this method to deal with those issues. As it is easy to add team members, it is also possible to remove team members as quickly as possible [7].

Possibility of assigning pre-defined and limited responsibilities. For control of the company's data, there is a tighter cloud access feature or granular permission for employees in order to secure data confidently. To be specific, each user of Onshape may already closely supervise teamwork and assist in safeguarding his IP at any moment by setting, modifying or cancelling the access rights of a person. For instance, the manager of the project might set a rule that says a worker recruited to the role of engineer can only edit a component design, but he/she is not able to export or exchange anything. If the management understands that the team cannot disclose a model outside the firm, the project will not be submitted without prior approval [7].

16.2 Possibility of Implementation of Concurrent engineering

Every PLM system has to provide collaboration tools such as those for communication. The following features of communicating and supporting by Onshape will be analysed to give solutions to issues in co-working and applications' functionalities.

Commenting on design. Moreover, Onshape's communication is built within the design environment. When senior engineers wish to comment and recommend design changes, they do

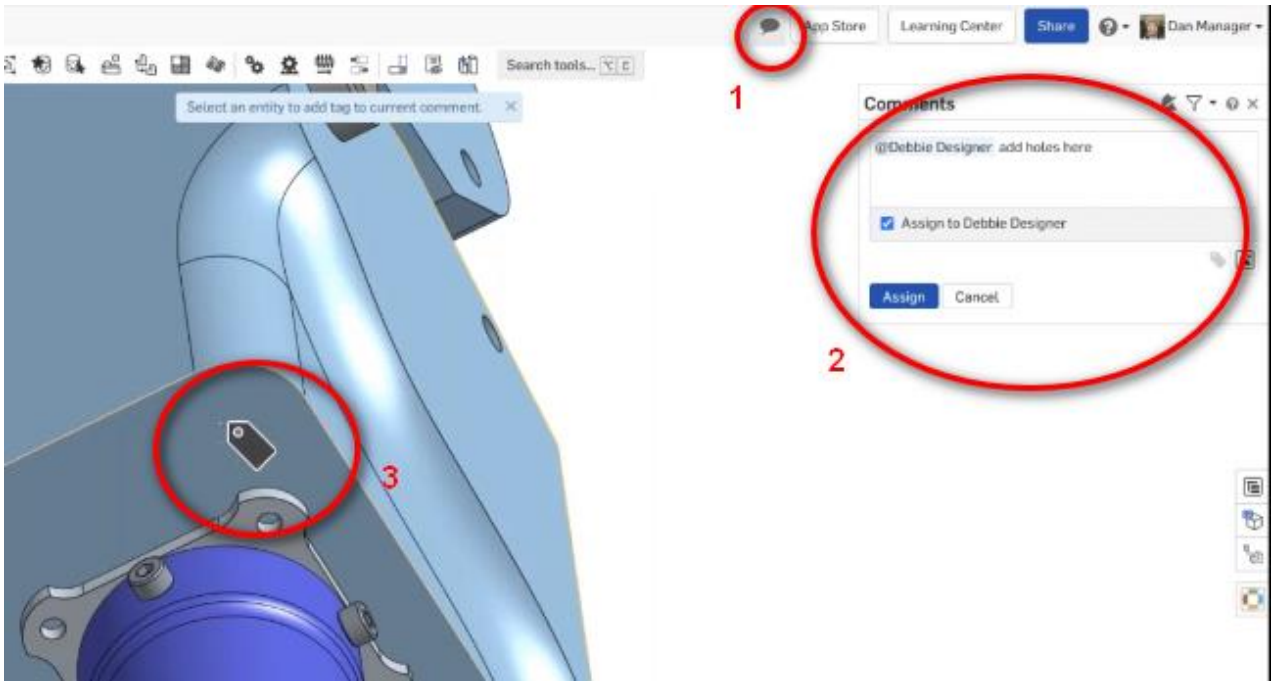

Figure 35 Communication process through specific comment section for recommendation. Image from https://www.onshape.com/en/resource-center/videos/solving-the-top-5-pdm-data-management-problems

not need to be present over the heads of junior engineers. A senior designer can do it through the comment section and tag on specifically mentioned surfaces of the part model to define clearly what he/she wants (Figure 35) [12].

Concurrent engineering with the platform. Full-cloud Onshape can be run in a web browser and multiple designers can collaborate in parallel over one component design. In addition, when someone makes editing or works on a specific part design, everyone, everywhere can immediately see it during the process. There will not be any obsession about overwriting each other's work and as mentioned above it will also allow working from multiple locations. Co-Design in parallel works like in Google Docs or Google Sheets, where everybody can instantly see each other's work, and there is no need to wait for someone to finish designing the model. Everybody can save time and effort by acknowledging what their partner is carrying out [7] [11] [12].

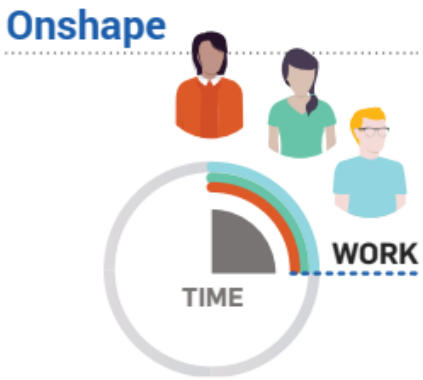

Figure 36 Time decrease due to Concurrent engineering. Image from ' An introduction to agile product design by Onshape'

Check-in and Check-out within CE. As stated above, in typical PLM systems, if there is an Engineering Change Order (ECO), the designer has to do a check-out for access into the model

design and check-in for exit from the file design after modification is finished. However, with Onshape, there is no check-in and check-out, which takes time since every design change is recorded. In other words, Onshape provides limitless redoing/undoing and a total audit trail of who carried out what and when. Consequently, it will be smooth to deal with conflicts when they occur. Every engineer can do his own version of design change in parallel by implementing Concurrent engineering methods [7] [11] [12].

17. Product data management in Onshape

A 3D CAD system will generate complicated interconnections between different types of files, and one of the primary tasks of Product Data Management software is to handle these interdependencies.

17.1 Approval process of design models

When junior or lower-titled engineers complete their tasks in designing their component or virtual assembly process, they will need approval from higher-titled senior employees or engineers in order to proceed with the component into production. In typical PLM systems, the approval process may require even more than one day. Onshape offers a quick approval process through its platform, whereas senior workers can access the platform when a notification comes through their tablets or smartphones in order to give the approval to proceed further without even installing an application. Moreover, it avoids bureaucracy and resource-consuming paper documentation for defining responsibilities. It gives comfort to the project manager or CAD administrator to know which files or documents are awaiting confirmation and for how long those documents have been in those conditions, and who has to give approval [7] [11]. Workflows integrated with release administration and approval may be adapted or customised to suit the business operations of most businesses.

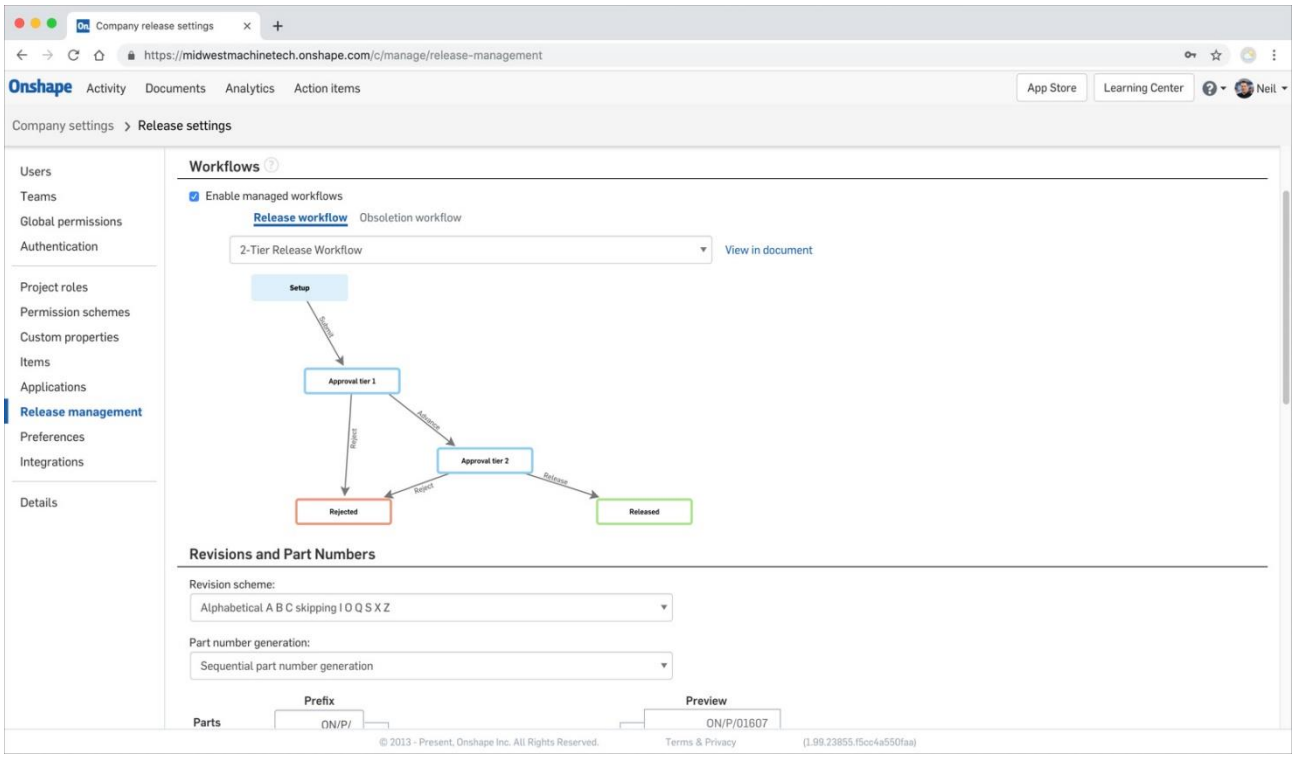

Figure 38 Approval workflow demonstrating state of document and responsibilities of workers for approval. Image from www.onshape.com/

Parts, assemblies, drawings, configurations and any other task data may be automatically managed in accordance with a predetermined release scheme. Engineers can return and refer to any released material at any time. For any combination of components, assemblies, settings and other items, users can produce a planned delivery in a single release. Moreover, while a release claim is made and authorized, users may keep on working. (Figure 37) [35]

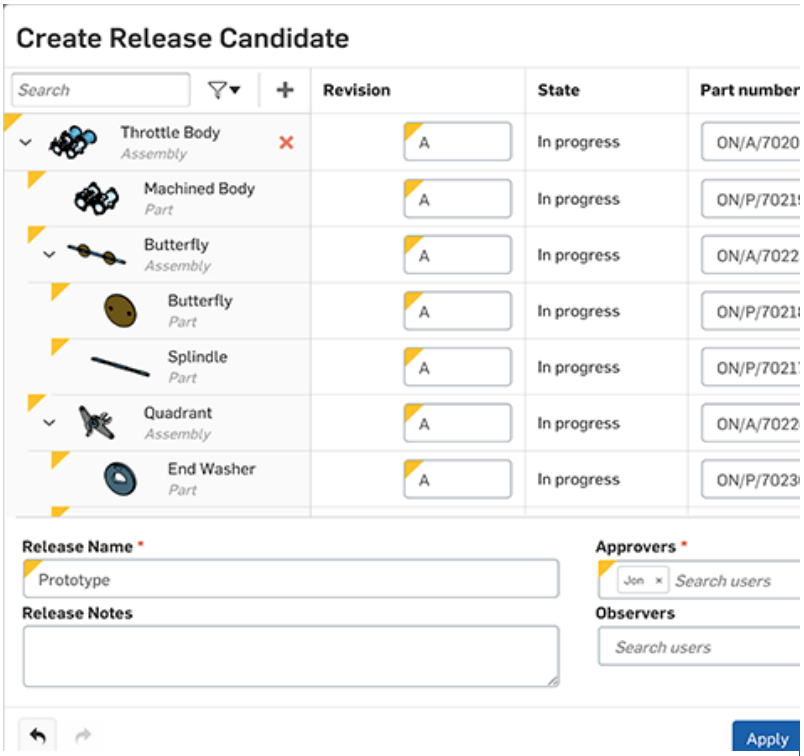

Figure 37 Release workflow where it is possible to create approver and customize release files. Image from https://www.onshape.com/en/features/product-data-management

17.2 Comparing

The problem of identifying what has changed in a particular design over time is an essential component of product design and data management. The Compare function of Onshape allows users to view both these changes quickly and simply via a textual list and visual clues. Users may compare changes among versions, workspaces and even points in part or assembly edit history. Users may not only observe the graphical change but also the particular CAD characteristics utilised to evaluate the various versions [35] [17].

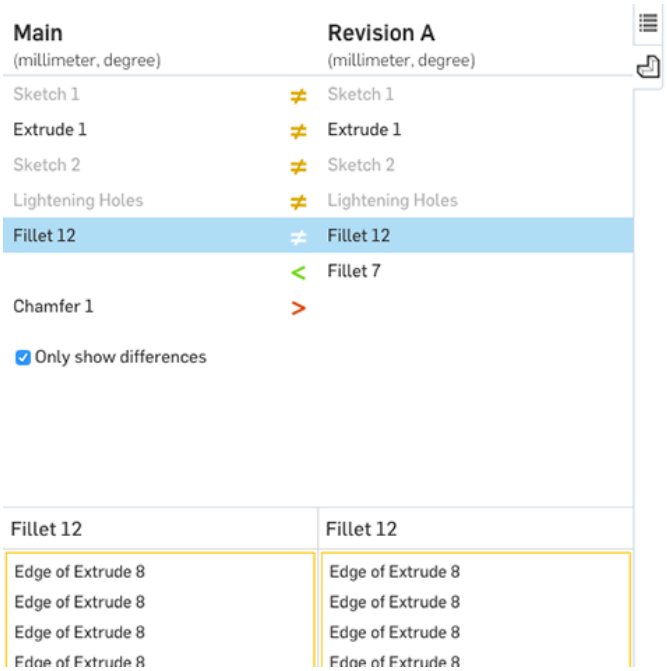

Figure 39 Compare function of Onshape between two parts. Image from https://www.onshape.com/en/features/product-data-management

17.3 Easy recovery from Mistakes and Automated backups

Onshape is the unique CAD system in the world that has a history of every activity in a centralised database. Every member of a design team has more responsibility and knowledge of the accomplishments of their colleagues. In addition to a view of who is doing what, the editing history of Onshape lets you see or recover your part design from any previous design phase or version due to the absence of a "save" button. This saves a huge amount of time comparing rapid prototypes and helps you recover from errors quicker and smoother [7]. The Optimal view of Version history allows easy management and control for time-saving when there is a search for a specific design variant. Moreover, when there are multiple copies of one file going around in different gadgets of partners and engineers with different methods of exchange of files, the abovementioned feature gives the opportunity to determine which design model is actual or real and which is not so [11]. According to Marco Cantamessa [6], these methods allow technological answers to be extensively sought and somewhat inexpensively, instead of depending on previous knowledge, through trial and error. It is possible for the roles of some crucial employees to be gradually reduced because similarly inexperienced people can do experiments and innovate with simulation and virtual prototyping tools even without having a comprehensive communication system that provides insight into the possible solutions.

17.4 Data format

Another major distinction is that Onshape does not utilise files that instantly reject the most irritating CAD and PDM problems. It does not employ a relational database like other PDM systems do to store design data. A relational database (also referred to as the SQL database by means of the transaction language that is used to add, modify, remove, and locate data) maintains information with strict schemes in set tables. This restricts what the database can

perform and what data it can hold. Onshape employs a document-oriented database model (NoSQL) supporting any data type with fully configurable schemes in any format.

It is a very powerful and widespread non-relation database type that is used for big data applications and other data processing activities that do not fit well with a strict relation model. A non-relational database design is composed of collections and documents instead of utilising tables and rows such as relational databases [11]. Rather than utilising conventional 3D part, assembly and draft documents, it uses cloud-native data (even though drafts are dwg/dxf suitable) [34].

17.5 Limitations of Cloud-based CAD

As previously said, a large number of organizations are currently using well-established CAD systems. It may be challenging to apply a new working method. Bulk subscriptions for big groups of students may be challenging to obtain, as SaaS products tend to emphasize individual subscriptions and companies. Onshape, on the other hand, lacks cloud-based modelling and analysis features like Fusion 360.

Many conventional CAD individuals may find it too much of a procedural adjustment to use cloud documents instead of conventional component and assembly files. Engineers and designers with suitable surface and solid modelling abilities utilizing well-known applications may also be sought by organizations.

In such a tiny and developing sector, cloud-based CAD may not be appropriate just yet. Although conventional CAD may be utilized offline, a bad network or a weak wifi signal might interrupt cloud-based CAD productivity that relies on efficient workflow [34].

17.6 Imported component design data

CAD data may be imported by the user in neutral and natural file-formats including STEP, Parasolid, JT, SOLIDWORKS, CATIA, NX, Creo or Inventor, and preserve legacy CAD information and modify it using Onshape's strong capabilities of direct editing as appropriate [36].

18. Enterprise management through Cloud-based platform

Onshape Enterprise is the premium product portfolio for advanced product departments that want to work quickly without sacrificing data control. Onshape Enterprise is a special Onshape scheme that enables a corporation to acquire the scheme with aggregated billing for numerous users.

18.1 Real-time Analytics section of PDM of Onshape

Within the system of Onshape, there is a large Analytics section that supports data management of the enterprise for complete reporting and resource control. In the following parts, some important sections of Analytics will be discussed and analysed for effective implementation and

reporting to know the actual state of the enterprise. Some basic parts will be discussed in detail and others only with important usage points.

18.1.1 Activity overview

Each enterprise analyser needs a complete real-time overview of the state of activities ongoing in the organisation to decide and choose a strategy optimally. For this purpose, users of the

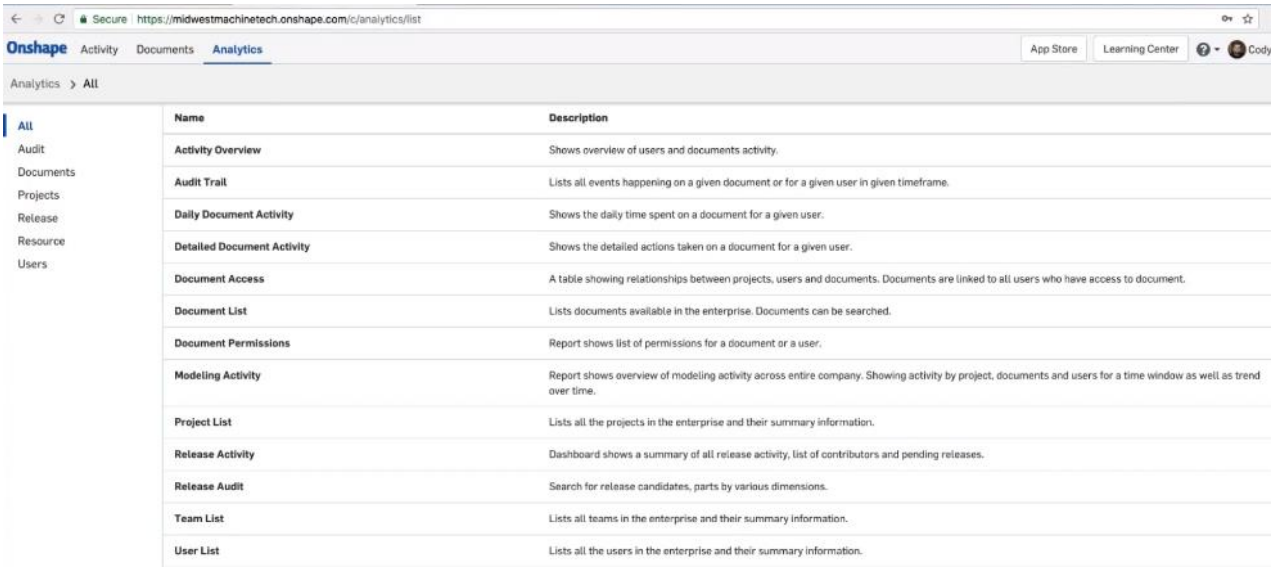

Figure 40 List of each report section in Analytics part. Image from www.onshape.com/

Onshape platform can easily get a recent real-time report of the whole activities and overall condition of the enterprise and its projects. The report file can be downloaded in either pdf or

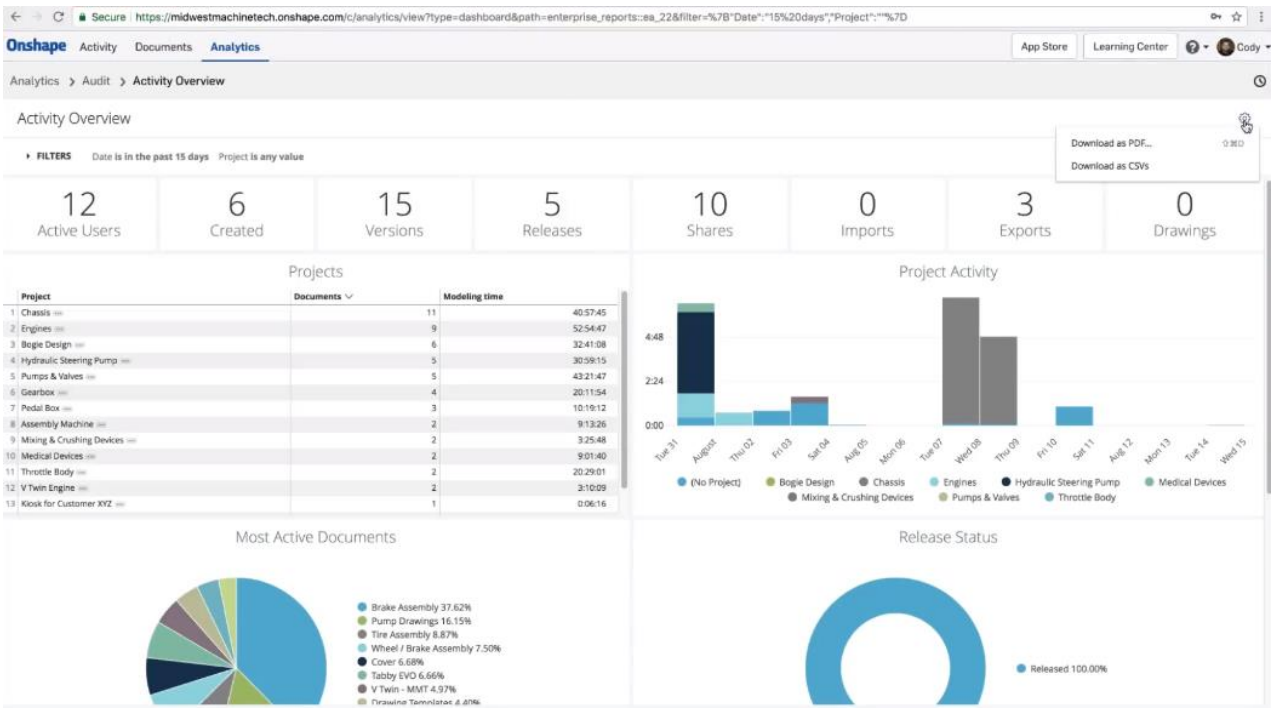

Figure 41 Complete activity overview demonstrating the state of enterprise such as projects' state and etc. Image from www.onshape.com/

CSV format, based on the requirements of the manager. The Activity overview demonstrates the state of projects with the number of documents created, a number of active users, documents created, releases, versions, shares, imports/exports, drawings, most active documents, daily

activities, easy-to-read graphs, and release status [37]. Moreover, this helps company managers plan beforehand and predict enterprise activities based on past and current data, identify bottlenecks in activities, allocate resources better, make informed decisions and accelerate time to market [35].

18.1.2 Audit trail

Onshape's Audit trail illustrates lists of all events happening over a given timeframe. Specifically, one can filter and need complete events in recent days. In the result, it will show every single event: document releases, share, export/import events within documents, etc. For example, a guest or contractor with an enterprise has limited access to a specific document. So, if an enterprise user wants to know if that guest or contractor shared that file, the audit trail will show it and save every activity carried out by all users. It is usually done through filtering based on the wishes of the user [37].

Other sections of Onshape Analytics

- **Daily document activity** illustrates the daily time spent on a document by a given user
- **Detailed document activity** demonstrates the detailed actions taken on a document for a given user.
- **Document access** a table showing the relationships among projects, documents, and users. Documents are connected to all users who have access to them.
- **Document list** lists available documents in the organization. Documents can be searched for.
- **Document permissions report** demonstrates the list of permissions for a user or document.
- **Modelling activity** illustrates an overview of modelling activity within the entire firm by demonstrating activity by project, documents, and users for a time window and trend over time.
- **Project List** shows the list of all the projects in the firm and their summary data.
- **Release activity** shows a summary of all release activity, lists contributions and awaiting releases.
- **Release audit** Look after release candidates, components by diverse dimensions [37]

18.2 Security

The safety of the Cloud Onshape platform is handled by additional standard security features like 2-Factor Authentication (Figure 42) (2FA). When authenticated, each enterprise user cannot access all data, and he/she can enter only projects, folders, or individual files that were given allowance to edit or view. The minimal security requirement is that every user must own their

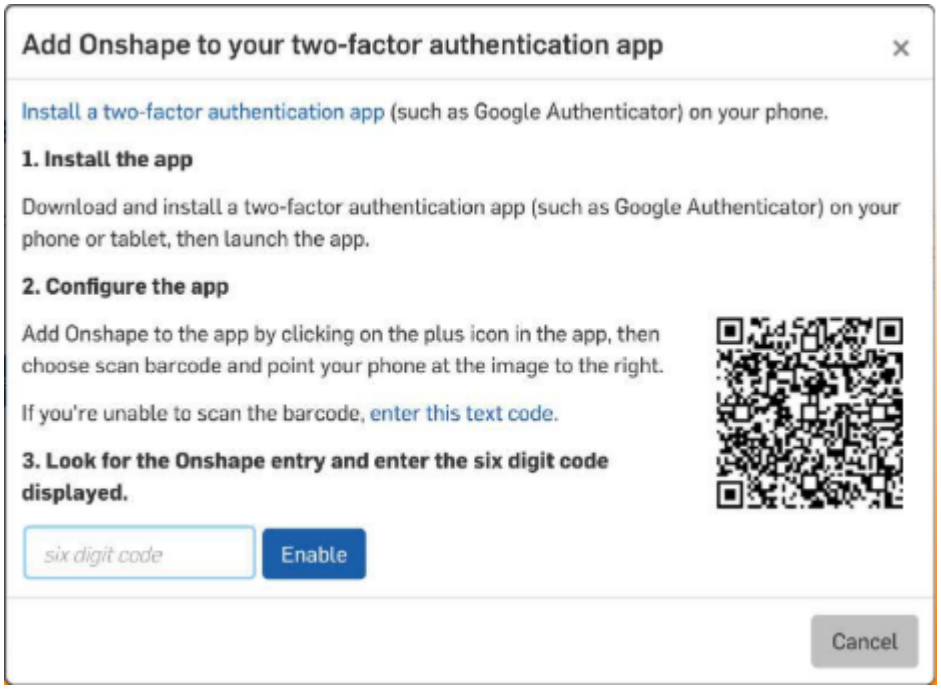

Figure 42 Additional security property such as 2-Factor Authentication (2FA) available as standard. Image from www.onshape.com/

own unique password and username and have to sign in to the PDM system before they are able to enter any firm data [11].

Encryption. All data in Onshape are stored using AES-256 (Advanced encryption standard [2]) encrypted storage. TLS v1.2 is utilised for all communication between internal computation servers and the internal databases containing format documents. For communications between customers and their service, they reject weak cypher suites and prefer stronger ones, whereas strong cypher suites are used by Onshape internal servers [38].

Password management. Onshape never clearly saves customer passwords. They use strong, one-way hashing algorithms so that the authentic password cannot be recovered even though onshape's internal password storage is broken [38].

18.3 Onshape Part Studio

To generate and modify parts, surfaces, and drawings, an Onshape Part Studio is utilized as a container. There are three main components to the Part Studio: the Feature toolbar, the Feature list, and the graphical section that houses the design. This is a design environment, not a model, for developing pieces that need to hold similar references, such as assemblies. Part Studios exist

[2] A special requirement for the encryption of electronic data created in 2001 by the U.S. Institute of Standards and Technology is the Advanced Encryption standard, commonly known as the Rijndael.

for desktop, iOS and Android with limited functionalities so the gadgets are capable to hold them [36].

19. Other tools or products by Onshape as a solution to PLM issues

In the following sections, additional cloud-based applications will be analysed and discussed in order to explore solutions to product lifecycle management issues. They are all connected and integrated with each other and purchased separately according to the needs of the enterprise administrator or new user.

19.1 OpenBOM (Integrated cloud-based application)

A CAD BOM is a set of the components and materials used to design an assembly model. The tables provide producers, management staff and contractors with a deeper understanding of the design that the bare model can offer, and are extremely useful to all stakeholders. Between the different components and assemblies of the CAD model, viewers can comprehend the connections through the CAD BOM [39].

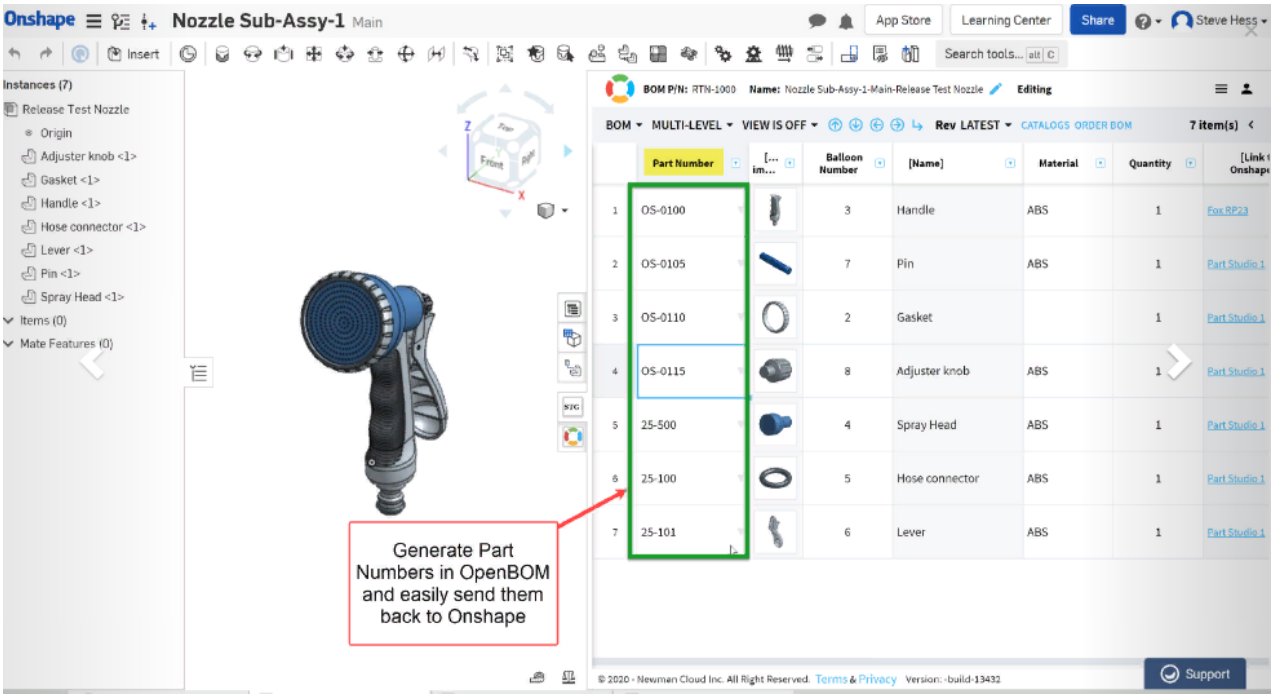

Figure 43 A view of Bill of materials in OpenBOM Onshape platform with its table and instances list for easy control with automatic numbering parts. Image from www.onshape.com/

To manage and distribute CAD BOMs (EBOM, MBOM, XBOM), categorise and maintain a worldwide item catalogue, allocate Part Codes, and work with subcontractors and partners, OpenBOM is a SaaS cloud PLM software solution. It also organises and manages components and suppliers and connects them. Extended companies will benefit from using OpenBOM because it offers teams the tools a firm needs to do things like precise order planning, rapidly producing Purchase Orders (POs), managing inventory and QOH (Quantity on Hand), and more.

Using OpenBOM's share command or OpenBOM Team/Company access control and sharing settings, an administrator may make his data accessible outside of Onshape and share it with any external partner in different formats such as PDF, CSV, XLS [40].

Real-Time Updates to CAD Bill of Materials. In the Assembly model, CAD BOM data is accessible and modified directly in OpenBOM. Modifications to the assembly model update the table in real-time with synchronous editing vice versa. The cloud-based CAD data management on Onshape enables the design and OpenBOM to update buying agents, assembly engineers and everybody else shared in the design of their individual equipment simultaneously in real-time. As a consequence, the enterprise's bi-directional data exchange is always synchronous with the condition of the firm's assembly model, always delivering an exact description of the product.

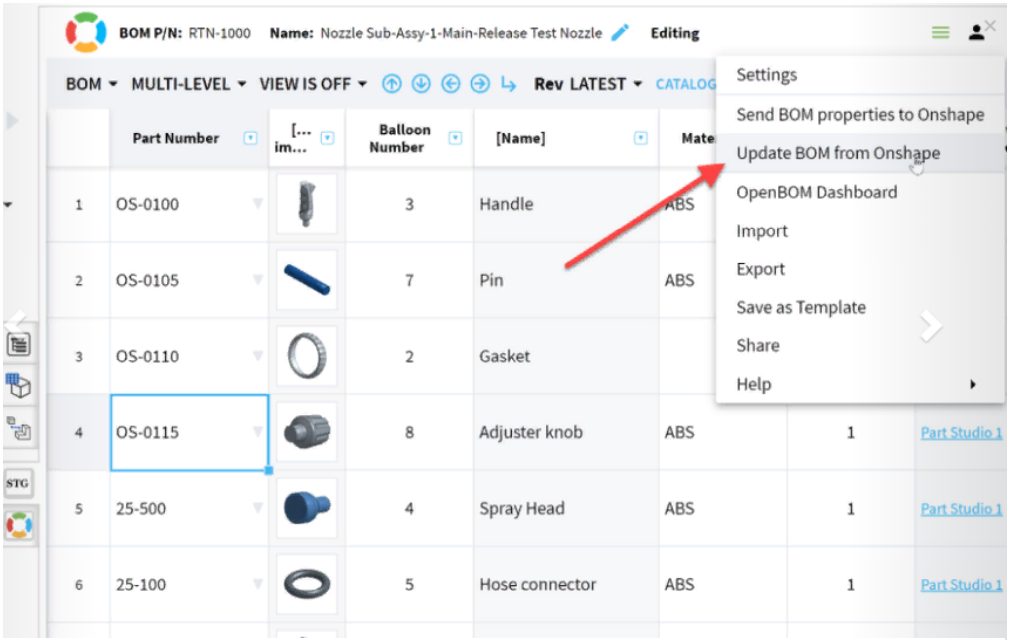

Figure 44 Easy real time update process of BOM from Onshape CAD. Image from www.onshape.com

If necessary, the CAD BOM tables may be put on a drawing kept associative with the latest changes and any relevant field from the table can be shown using smart balloon callouts [39]. Moreover, as in Onshape CAD, OpenBOM allows you to track BOM modifications, handle BOM revisions, and create change reports with the opportunity of simultaneous editing like in Google docs [40].

19.2 Cassini's Solidworks to Onshape migration tool (Connected Desktop app)

The Migration Tool in Cassini enables clients to move data from SOLIDWORKS to Onshape. Duplication of the data, because the normal import of Onshape generates a new component with every import, is an issue for the clients when transferring the data. Cassini offers a simple and straightforward solution for the migration of your old information to Onshape. The migrating tool also maintains the SOLIDWORKS and SOLIDWORKS PDM directory structure. In addition, metadata such as custom attributes may also be transferred to Onshape. The following features are functions of Cassini's migration tool:

- Wholesale transfer from separate folders or PDM repositories
- Removal of duplicate component design
- New versions for modified documents in Onshape
- Transfer of customized attributes
- Generate drawing views (DXF) for components and assemblies
- Development of Bill-of-Material
- A large dataset in unsupervised mode

- Transfer Summary with email alert

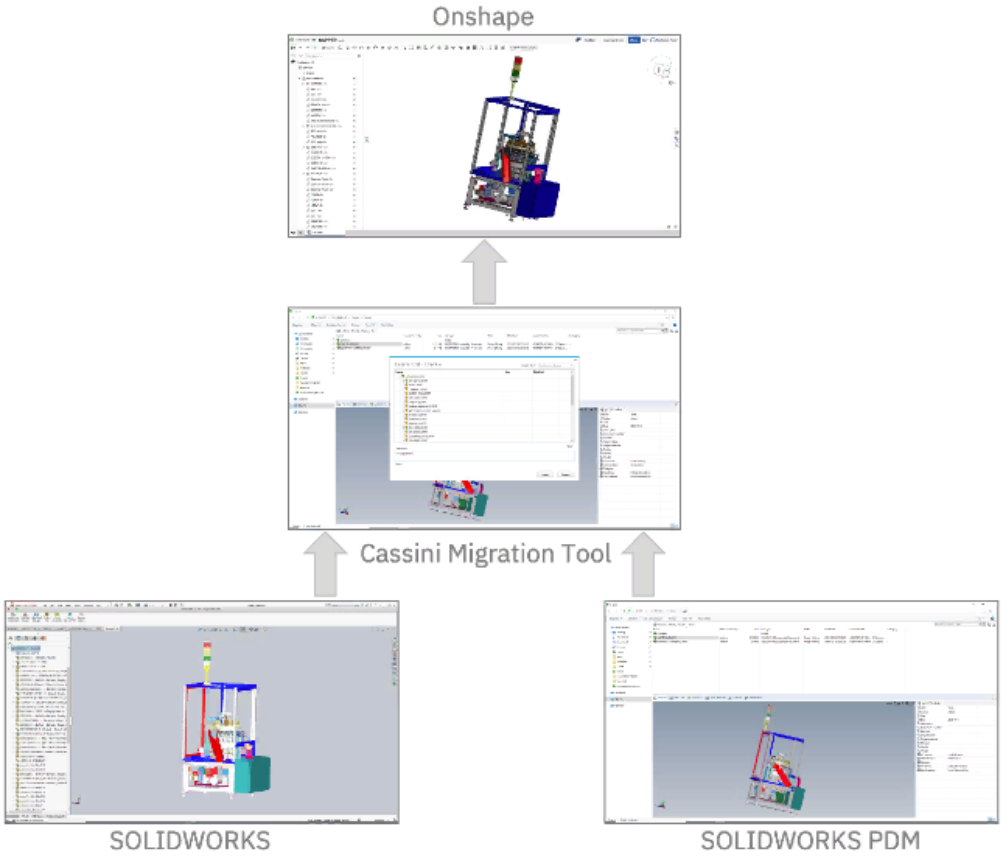

Figure 45 The structure of Tool's functioning method. Image from https://appstore.onshape.com/apps/Data%20Management/OR2Q3CQMIUVHUKAWN65HJ6UAEOGEDQGSZTDAJCI=/description

How does it work? Cassini's migration tool is desktop software that transfers data from Solidworks or Solidworks PDM to Onshape. In the case of large datasets, it can be switched into unattended mode. Once the process of migration is completed, a summary of the transfer is sent as an email to notify the data holder. If a user wants to implement and transfer customised attributes, he or she can provide a mapping of Onshape and Solidworks properties. Solidworks or its PDM is required for the application to run, and it is only available on Windows 10, with no support for other operating systems [41].

19.3 OneIPM Data management (Cloud-based application)

OneIPM is a unique and graphically impressive method of examining documentation in an enterprise and managing all projects and tasks on an Onshape basis. It allows in-depth examination of documents, component variations and product structure with a broad experience in viewing. Moreover, it offers management of projects and tasks while preserving complete linkage with Onshape documentation such as components and assemblies. The platform with functions and other features was created for Onshape's professional non-cad team members with its usability [42].

For experienced Onshape users, OneIPM has functions such as:

- View documents, assemblies, part studios and components in a unique manner.
- See a timeframe for all versions of a part. Or select an overview to see how the component has changed through time.

- See the typical flat or indented (BOM) sight of product assembly. Alternatively view them in a linear or radial perspective of the visual, hierarchical/relationship (node) view (Figure 46).

Figure 46 Node view of Product clearly visualizing its components. Image from www.onshape.com/

- Utilize OneIPM as a Web-browser to open files in Onshape
- View the work tasks in your monitor and coordinate all your activities [43] [42].

Moreover, the cloud-based platform is very suitable for the implementation of agile methods such as Scrum or others with the usage of backlog view. There is no need to use another separate platform for project management. It is all integrated with the Onshape system, which supports private projects as well as enterprise-wide projects.

As non-CAD users, Management can allocate tasks and track the progress. The Finance section can evaluate component and assembly modifications in order to regulate seller prices. Marketers may collect photos of products, and support can offer engineers' opinions immediately, and the whole team may contribute to the growth of the project [43] [42].

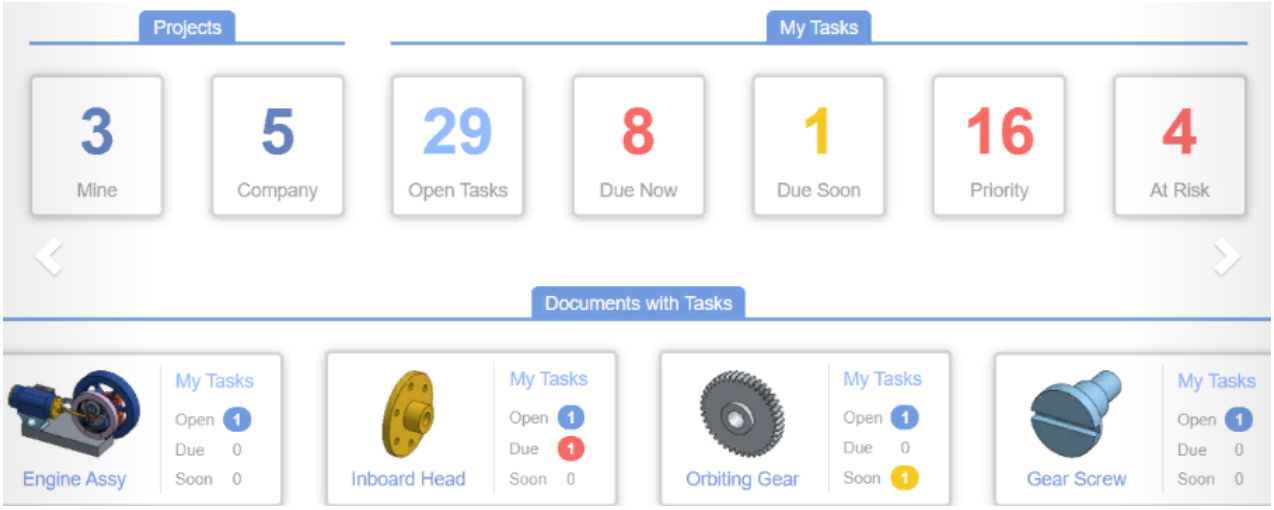

Figure 47 The user's project and tasks overview for monitoring their state. Image from www.image.com/

19.4 Cadasio (Integrated Cloud-based App)

This comprehensive software imports existing Onshape assemblies and components into the user's Cadasio account for further processing. Reducing printing expenses and increasing sustainability are all benefits of offering your items and guides online in 3D with Cadasio.

Figure 48 the view of workspace with assembly for creating project such as animations and presentations. Image from www.cadasio.com/

The reader of manuals may rotate, enlarge, and pan instructions, so the user may need less documentation. Nevertheless, exploding lines, labels, photos, and text can all be included in a user's Cadasio projects if they want them to. Technological interactions will be more engaging and up-to-date if users include links and attention-grabbing animations in addition to the text. It reduces time to market and enhances customer engagement and experience [44] [45].

How does it work? Once subscribed to in Cadasio, the user opens his assembly in Onshape and adds it to the workspace of Cadasio. A user can make or update a Cadasio project from his assembly. Then he can start creating 3D interactive technical interactions. As the application is new and free of usage, in the following discussions some drawbacks will be mentioned in order to avoid further new issues that may occur.

It is not possible to change the point of rotation, which is automatically fixed when the assembly is added to the workspace. The BOM becomes out of order when the user inserts an assembly, which makes it challenging to navigate and immediately find assemblies and components. The choice of lighting and finishes is limited. But with further updates, it has the potential to increase features and other functions for creating manuals and presentations [44] [45].

19.5 Assembly planning app (Cloud-based app integrated with Onshape)

Assembly planning app offers to make manufacturing and supply route of the product, to compute and manage manufacturing & supply costs and scheduling in order to get summary of Material needs to be taken into account schedule of manufacturing & supply and contribute complete BOM plus Routing information for **ERP/SCM/MRP** functioning [46].

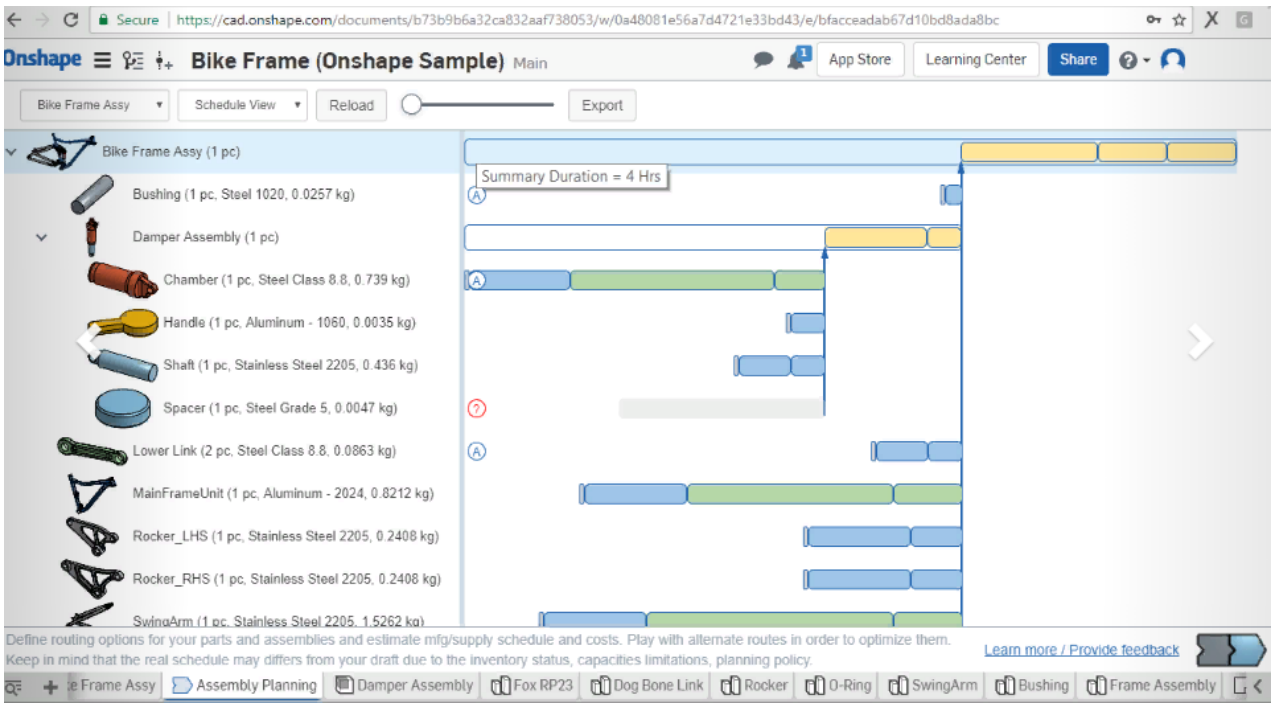

Figure 49 Onshape Assembly planning app view with Gantt chart and other crucial data for mfg/supply routing. Image from https://appstore.onshape.com/apps/Data%20Management/5WMOI4S2ZEMWPZZGCSIB66SVUUOILOMOBPWJP4Q=/description

Utilizing an assembly planning app integrated with the MRP/SCM/ERP infrastructure can definitely save time and decrease the number of errors when the user is responsible for routing and BOM. The simpler method of doing integration is exporting BOM plus routing as a JSON (this is an available feature when a "Pro" type purchase is made), then converting it to any format suited for enterprise MRP/SCM/ERP systems, and importing it there.

How does it work?

- In Onshape Part Studio, users may allocate material to a component. As a result, users will have access to the correct summary material requirements at a later time. It's important to keep in mind that users may always develop their own Material Library if necessary.
- Depending on whether the first activity is for in-house made parts or buyable components, the user designates it as a "Material Supply" operation or a "Supply." Then he determines the supplier ("Business Unit/Work Centre" field) to use for the operation and inputs more or less accurate cost per part values. Costs-per-item often refers to the price of a single material or component. In return for submitting this, users will receive a list of the required materials soon.
- Users should plan operations with a more or less realistic time frame in mind and remember to include transit time and expenses in their budget. The time and expenditures associated with transportation can be included in other operations, or they can be created as a distinct "Transportation" activity.

- Components such as fasteners, which are always on hand, don't require a supply time to be set up.
- Typically, the user differentiates activities on the diagram by using colour to identify suppliers, floors, and work centres.
- The user can utilise the context menu to rearrange his operations if necessary. Create the new operation as the final one and then shift it backward if he needs to place it between other operations (up).
- Alternative routes should be planned. The user will be able to choose between the choices later on to optimise their manufacturing and supply timing and prices.
- Moreover, when the geometrical and other properties are changed by engineers, they can be updated through the 'Reload' active button. It allows for the elimination of ambiguity with suppliers and in-house manufacturers [47].

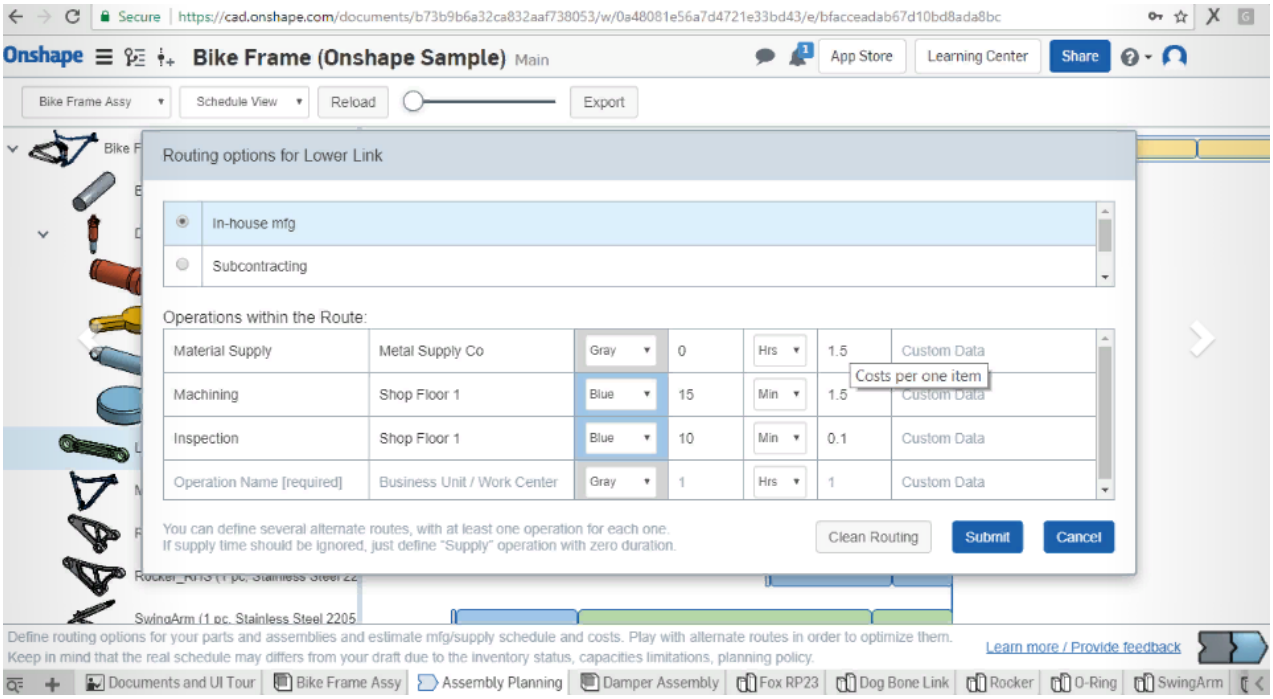

Figure 50 Allocating materials for routing options and customizing plan in the app. Image from https://appstore.onshape.com/apps/Data%20Management/5WMOI4S2ZEMWPZZGCSIB66SVUUOILOMOBPWJP4Q=/description

Onshape's Assembly Planning App does not handle the following aspects of a "complete" Material Requirements Planning, which are critical. They are the following: inventory levels and reserves, sales, purchases, manufacturing capacity limits, transportation and storage constraints, the calendar, the manufacturing and purchasing policy, and the budgeting timetable. Utilizing the ERP system in conjunction with the App is the better choice if a user wants to use the abovementioned absent functionalities.

19.6 OnScale Solve (Cloud-based app)

To solve the restrictions imposed by **traditional desktop** FEA (Finite Element Analysis) and CFD (Computational Fluid Dynamics)[3] simulation tools, OnScale Solve was developed by engineers for engineers.

[3] Partial Differential Equations may be solved using Finite Element Analysis (FEA), which has historically been utilised to tackle structural issues. A collection of methodologies known as Computational Fluid Dynamics (CFD) is better adapted to the analysis of fluid flow.

- Simulating engineering concepts with several physical variables quickly and easily.
- Restoration and meshing in automated CAD software
- HPC cloud computing capability that can be scaled.
- User-friendly user interface and operations that are seamlessly integrated
- Jupyter notebooks[4] and smart outcome analysis.
- Pricing is based on the number of simulations a user does.
- From any place or device, a user can work, collaborate, and exchange information just like in Onshape CAD.

Models created in Onshape may be exported straight into OnScale Solve via the OnScale Connector App, allowing users to use OnScale without ever having to leave Onshape.

OnScale Solve is built on the newest web browser technology and is cloud-native, resulting in a speedy, straightforward simulation process and directly linked to Onshape. Full automation of the meshing process frees the user to focus on the simulation challenge at hand. The user may interact with all of the cloud-stored obtained results data from inside the UI, and just the data required to produce diagrams, tables, pictures, and animations is retrieved. Numerical simulations and core-hour collaboration may be managed with ease using team and project dashboards. The feature of being cloud-native allows optimization through parallelization of single problems on the same machine (shared-memory) and many machines (distributed-memory), which gives freedom to users [48] [49].

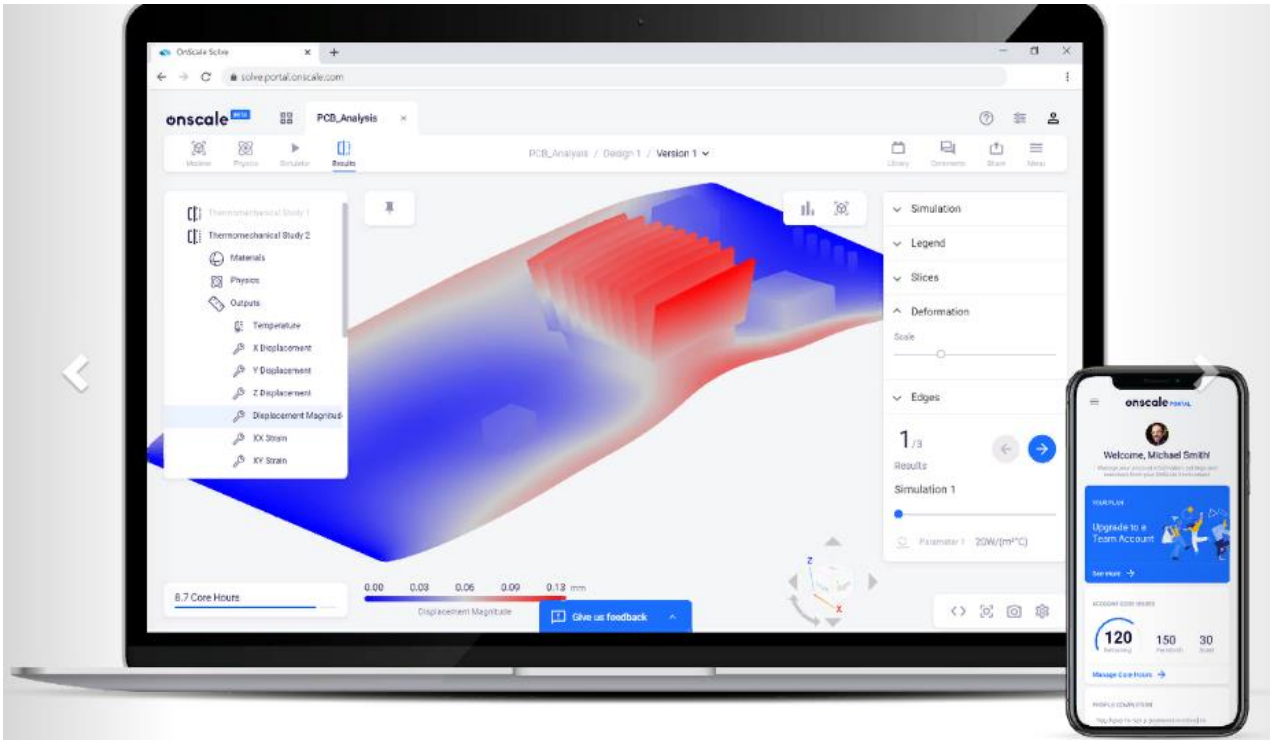

Figure 51 OnScale is Accessible through smartphones and desktop using web-browsers. And screenshot of application. Image from https://appstore.onshape.com/apps/Simulation/WK4WRLFPAIWTGRIPXTAYN5YJMMSIL7IG75LMOCA=/description

[4] Users may read and distribute documents with live code, equations, graphs, and narrative content using the free and open-source Jupyter Notebook. Data cleansing and transformation, simulating numerically, modelling based on statistics, data demonstration, and machine learning are just a few of the many applications that may be made with it.

19.7 Duro PLM Data management (Integrated Cloud-based application)

All of the firm's critical engineering and production data is consolidated in Duro's cloud-based PLM (Product Lifecycle Management) platform. Duro is designed to be implemented with a minimum number of steps to speed up engineering processes. Assigning component numbers based on PLM to Onshape parts and releasing authorized design changes directly to Duro's central hub using Onshape's current Release Management workflow are just two examples of how Duro enhances the importance of Onshape. Product information may now be exchanged with anybody in the organization, not just those with Onshape authorization [50].

19.7.1 Features of application with Onshape

PLM based part numbers. Onshape supports assigning PLM-based part numbers to components and subassemblies for Duro. Engineers can do descriptive searches and verification checks using Duro's component numbering scheme, which is based on categories.

Configuration Management. Onshape users may easily export component and assembly configurations. This mapping is done asynchronously by Duro when the user imports Onshape Configurations.

Release Management Integration. Using the Duro app for Onshape, users can submit authorised releases, sketches, and manufacturing files to Duro's central repository straight from the Onshape Release Management workflow.

*Automated exporting. It is possible to ex*port PDF designs and other manufacturing file types (e.g. Parasolid and STEP) autonomously when a release is created for any number of components and assemblies. Files are uploaded to Duro and made available to the public.

19.7.2 Features of Duro PLM

Change management order. The Change Order Management procedure at Duro is the smoothest and fastest. The time it takes for teams to evaluate and approve modifications has been reduced from days to minutes due to Duro. Workflows are simplified as much as possible not to slow down the tasks of engineers.

Automated part sourcing. The Auto-Sorting feature stores and processes part specifications, price, and production and delivery time from all major vendors of spare parts (e.g. Digikey, McMaster, Mouser, Arrow, etc.). It allows you to get notified as soon as pricing or production schedules alter in order to avoid missing out.

Open API. If the firm has 3rd party software and the company wishes to integrate it with Duro PLM, there is an intermediary API (Application Programming Interface) for that purpose [50] [51].

19.7.3 Updating data in BOM

It is possible to update BOM modifications that happened in components. When the user selects edit mode, the software asks whether to do it manually or import an excel spreadsheet. Moreover, after the update is completed, it is possible to save this revision in history in case it is needed, and the user has the opportunity to compare revisions with an understandable interface [50] [51].

19.7.4 Creating new product variants

It is also possible to generate new product variants in the applications, and these new creations will automatically notify relevant stakeholders. Just changing critical elements such as assembly

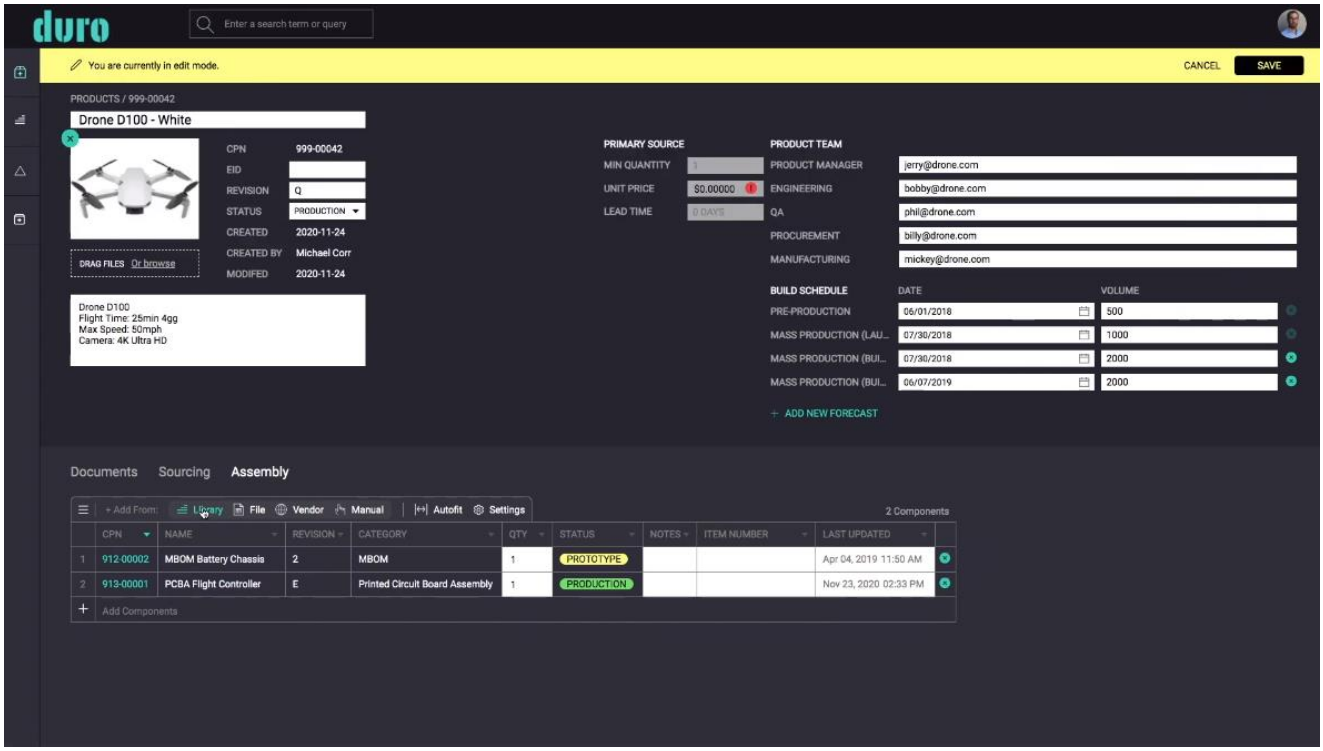

Figure 52 Generation of new product variant. Below there is table of assembly structure and contact data of other contractors for notification. Image from https://www.durolabs.co

elements and other component details is sufficient to complete the task (Figure 52) [50].

19.8 ARbase Augmented Reality for Onshape (Integrated cloud app)

With Onshape Part Studios and Assemblies, users can quickly build, modify, and exchange Augmented Reality (AR) designs.

Onshape Part Studios and Assemblies may be converted to Augmented Reality designs that can be seen on Android and iOS devices using ARbase, an Onshape software incorporated into the design software. Users may modify material parameters for a more lifelike portrayal by using the integrated program.

By saving the interactive virtual models to the cloud, ARbase makes it easy for users to share their work with others all over the world. ARbase's in-browser Augmented Reality viewer generates unique URLs and QR codes (Figure 53) for each model, making it simple to share and see other users' works [52] [53].

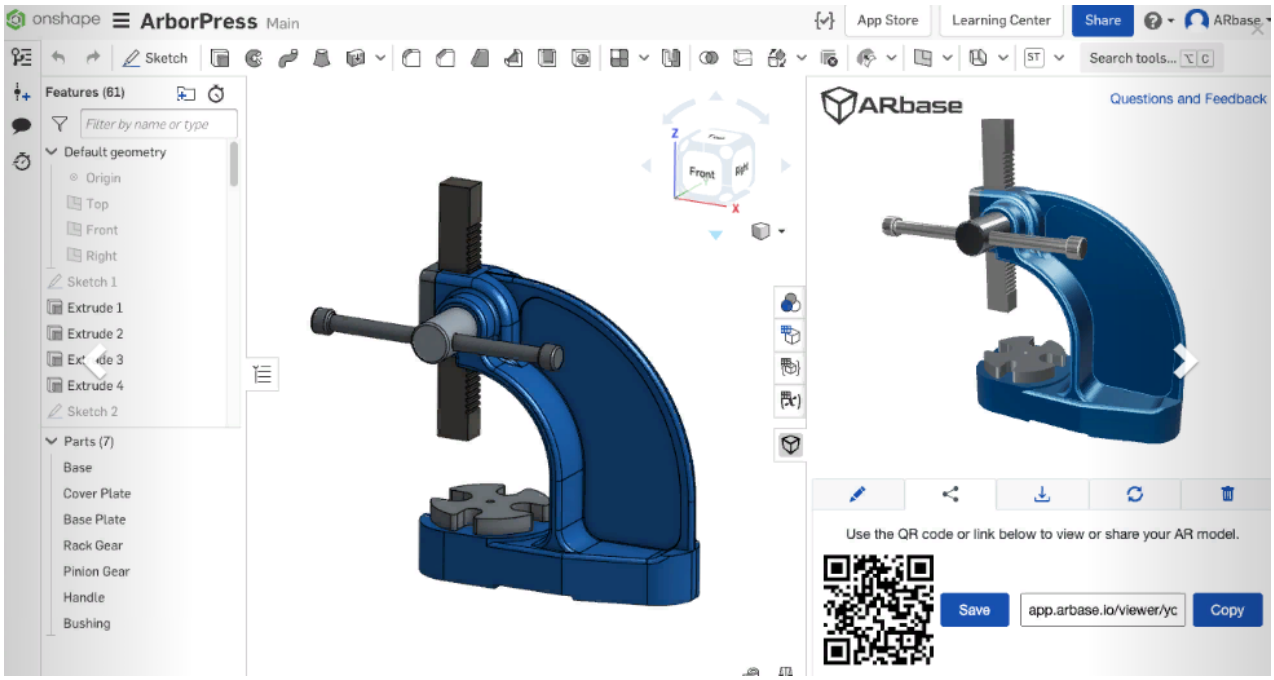

Figure 53 It is possible to generate QR or URL code to view design model in diverse devices. Image from https://arbase.io/#how_to

19.9 Phi Design and Documentation by Phenometry (Integrated Cloud app)

The Phi surface modeller is redefining the organic 3D Model with its cutting-edge technology. As a result of Phi's ease of use, top-quality, waterproof, and fine surfaces may be designed and manipulated in a short timeframe. On the newest internet browser technology, Phi is cloud-native and operates entirely within an Onshape Document window.

Curve-based modelling is made easier with the help of Phi's advanced, patented technology. Phi asynchronously and interdependently evaluates and fills in the surfaces derived from natural unrestricted curves users create. While other numerical infrastructures, such as Nurbs or SubD, have been developed for similar purposes, Phenometry's proprietary long-term R&D on n-sided surface patchwork provided the foundation for the Phi modelling operating system [54] [55].

19.9.1 Import & Export

It is possible to send Phi design models to Onshape Part studios with live updates by sharing in SPEP and STL formats. Moreover, users can import reference models from Onshape or STL, and drawings to use as references [54].

19.9.2 Design Manipulation

The user can edit the curves in whatever way he chooses to convey the design purpose, and smoothness and continuity can be added to the edges and faces. In addition, the designer is able to manipulate and make deformations in edges, faces adapt, and curved combs. Regional and global outcomes can be obtained by combining two distinct kinds of mirror actions. Make copies and attach several bodies together after importing them, joining or separating them as needed.

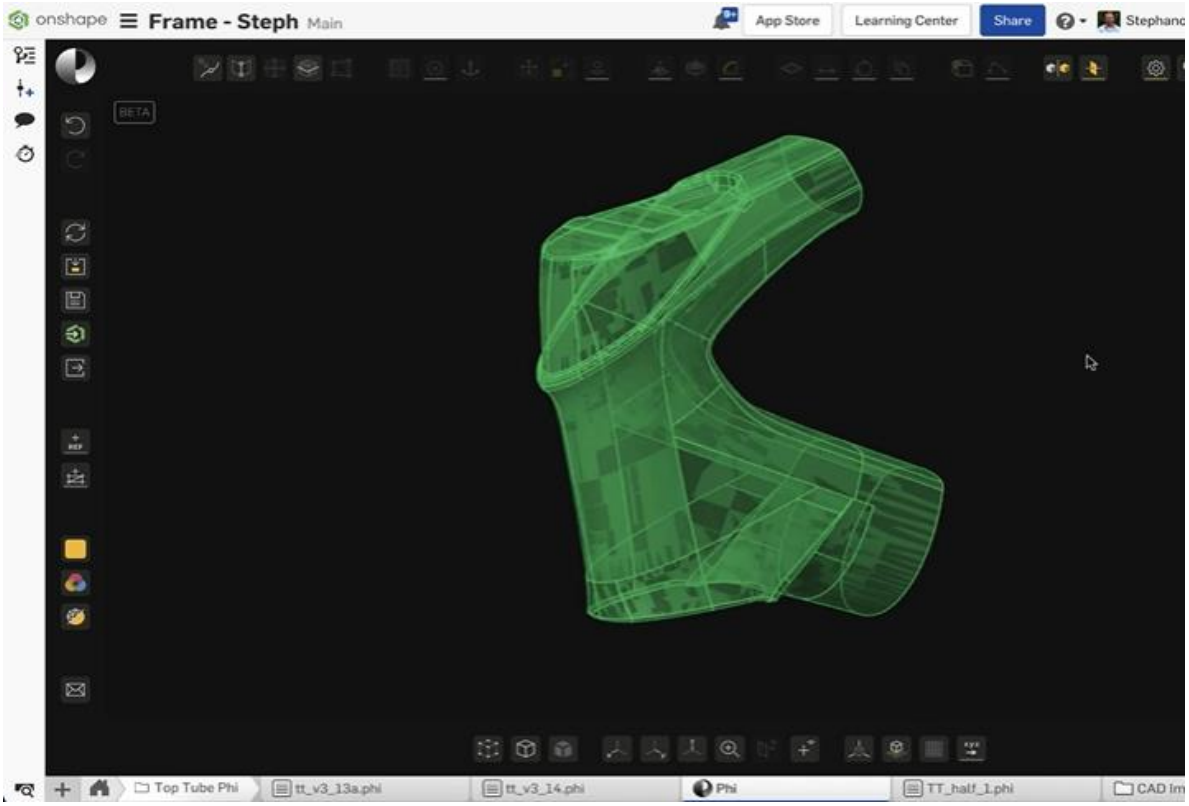

Figure 54 Working Interface of Phi design app integrated with Onshape app. Image from https://phi3d.com/

Pop-outs, bridging, cutting, and gaps among surfaces are all methods of altering volumes [56].

19.9.3 Engineering precision Precise and monitor moving, positioning and scaling.

Using accurate interfaces, the user may move and resize items, as well as build and configure circular and linear forms. Coordinates, workspace units, grids, snapping, accuracy, shadowing, and aligning are all displayed in 3D with this application. Smoothness and consistency among edges and surfaces may be applied, and freeform forms can be precisely created [55] [56].

19.10 Link Tab by Lou Gallo (Integrated Cloud app)

Users may generate hyperlinked tabs in existing Onshape documents with Link Tab, an integrated cloud tool. It is possible to use an Onshape document as a doorway to relevant information and services with this technique. Google applications and YouTube are two examples of services that will automatically attach and make available right in the Onshape Tab. Another option is to use the Onshape Tab to open the hyperlink in a new browser tab.

It is, for example, a useful app for keeping track of any subcontractor websites or information related to designer's models. They can use it for every standard purchased component that goes into their assemblies so that data sheets, pricing information, etc are easily available with one click from within Onshape. The only drawback can be that another user has to install it using a

Google Drive account, so if the user's enterprise does not utilise G-drive, they miss out on some features [57].

19.10.1 Tested programs:

- Apps from Google (Sheets, Docs, Presentations, etc.)
- YouTube
- Todoist task manager (project management software)
- Atlassian Jira and its companion websites

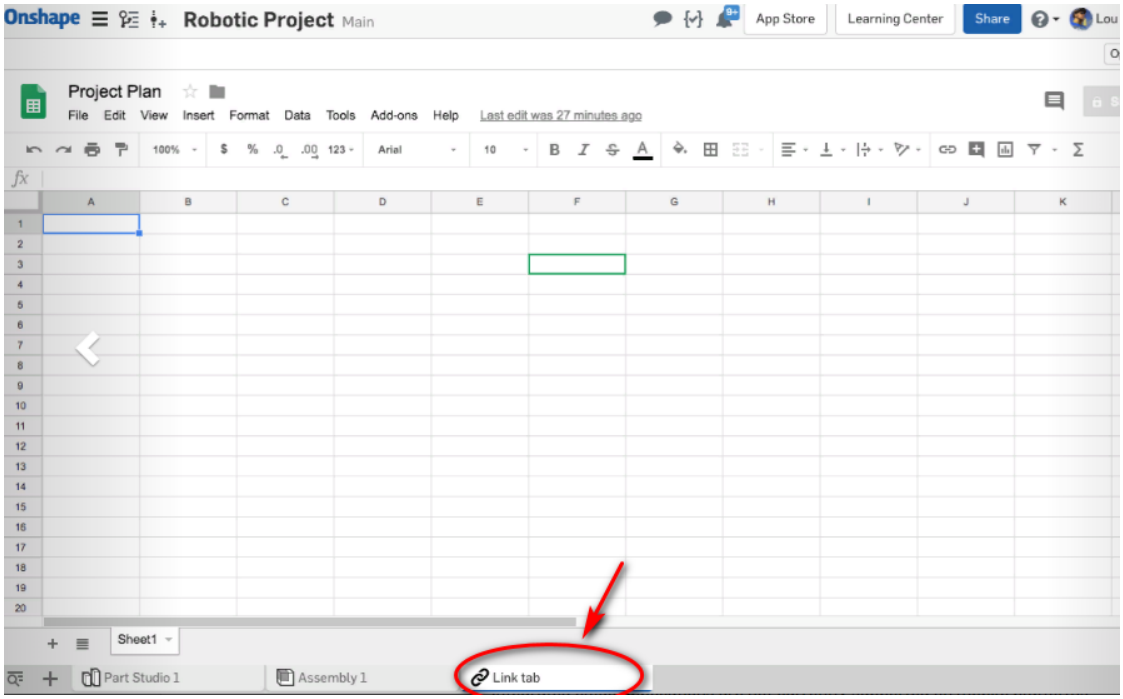

Figure 55 Entering new https URL link of Google sheets in order to connect the tab. Image from www.onshape.com/

19.10.2 Partial support (if a user can find the correct embed link)

Microsoft's Office 365 (Typically needs to be shared and extract the embed link from the share dialogue) and Trello which is a project management tool (Partial support with some automatic link reformatting) [57].

19.10.3 Restrictions.

Only HTTPS-compliant third-party websites can be embedded. In addition, third-party services have control over the ability to connect to them, and some sites specifically prohibit linking. The link will be kept in the Onshape tab if it can't be included, and it may be accessed using a click in the tab's top right [57].

19.10.4 Requirements

To use this app, a user needs a Google account that's signed in and active. In order to access the Link tab page after installing the programme but it is blank, users must first log in to their Google account. This process will be improved soon [57].

19.11 Onshape BOM for Google sheets Data management (Integrated Cloud app)

The Onshape BOM for Google Sheets Add-on app links up a user’s Onshape account and retrieves bills of materials (BOMs) from Enterprise’s assembly list. When information is retrieved,

the Google Sheet is filled with all the essential metadata from the assembly containing: Created by, BOM creation date, Modified by, Creation date (UTC), Modified date (UTC).

If users make any changes to the Onshape component or assembly metadata, they will be reflected in Google Sheets as well. Presently, it is only possible to retrieve 'Parts-only' BOM within this add-on. Linking Google sheets to Onshape's full-cloud CAD allows well-managed centralization of BOM [58].

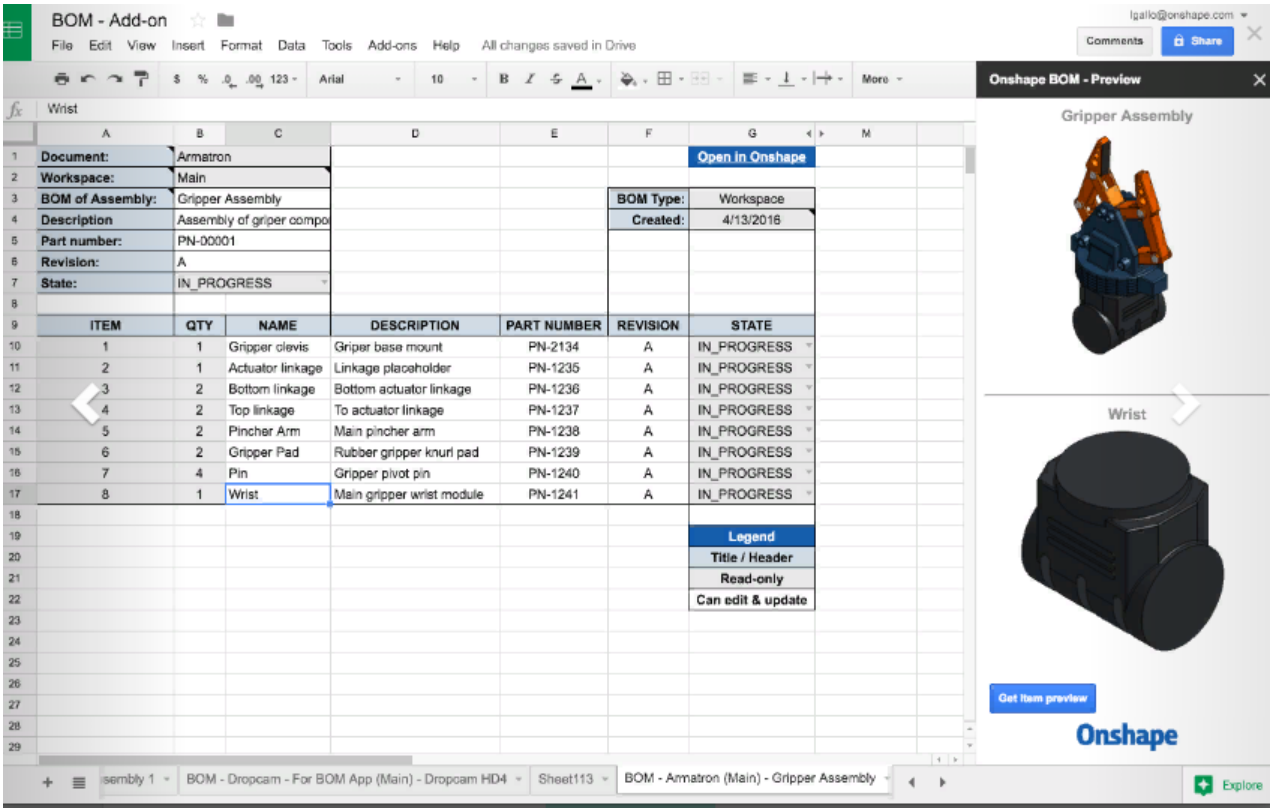

Figure 56 Extraction of BOM list from Onshape BOM app into Google sheets. Image from www.onshape.com

PART V: FRAMEWORK FOR PLM-ERP-MES INTEGRATION

20. ODOO software (separate cloud platform for PLM-ERP-MES integration)

Odoo is a package of company administration software solutions covering, for instance, CRM, e-commerce, billing, accounting, production, warehousing, project management, and inventory management, product development, ERP and MES. The Community version is a free program, distributed under the GNU LGPLv3[5]. The Enterprise edition offers exclusive added features and services. The source code for the framework and key ERP modules is controlled by Belgium-based Odoo S.A. Odoo is accessible, including both on-premise and suitable SaaS settings.

20.1 Introduction to ODOO

On-Demand Open Object (ODOO) is the abbreviation for the term ODOO. There are strong linkages between the enterprise and open source sectors and ODOO's business administration software. The program is built on top of an open-source ERP system that is both inexpensive and user-friendly for other people. Many contractors, SMEs (Small to Medium Enterprises), and

[5] The Free Software Foundation (FSF) has released the GNU Lesser General Public License (LGPL), a free software license. Developers and corporations can utilize and incorporate LGPL-licensed software components into their own (even proprietary) applications without having to provide the source code for their own parts under the conditions of a robust copyright license.

corporations have taken advantage of ODOO's flexible design by extending its applications and modules. There are features for PLM as well as notable MES features available inside its

Figure 57 Odoo open source ERP system (Adapted from synconics)

production app, making this program suitable for explaining the integration of these two systems.

All the sections of the ODOO application are shown in the image. These systems are capable of managing different manufacturing and business processes such as billing, accountancy, production and purchasing as well as PLM (Engineering change orders) [3].

20.2 How it works?

The program may be downloaded and installed on most x86 PCs, particularly Windows and Linux ones, using the Web Browser. To link to the internal network with the ODOO system installed on a computer, the SQL database management program must also be installed. This data management application stores all of the files and documents generated by the ODOO application. The program serves as a server for other computers on the network, which may then be accessed via a browser. In order for the computer software to operate, the gadget under use

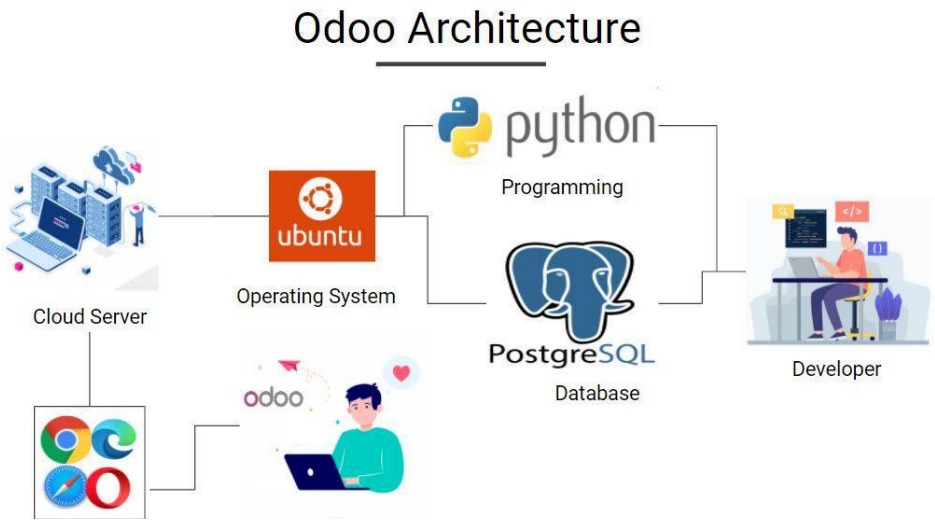

Figure 58 ODOO Architecture flow diagram (Adapted from Prothai technology)

must remain on and linked. The computer program might be devoted to a server or a running desktop when in use.

There are two ways to set up the device to execute the program. In the first place, you may make advantage of ODOO SA's hosting solution. The platform would be maintained by them, and all of the work-related data would be saved in their cloud as a result. A lot of small businesses rely on this service provider, especially those that employ modules connected to their websites (includes management and building of web pages and e-stores) [3].

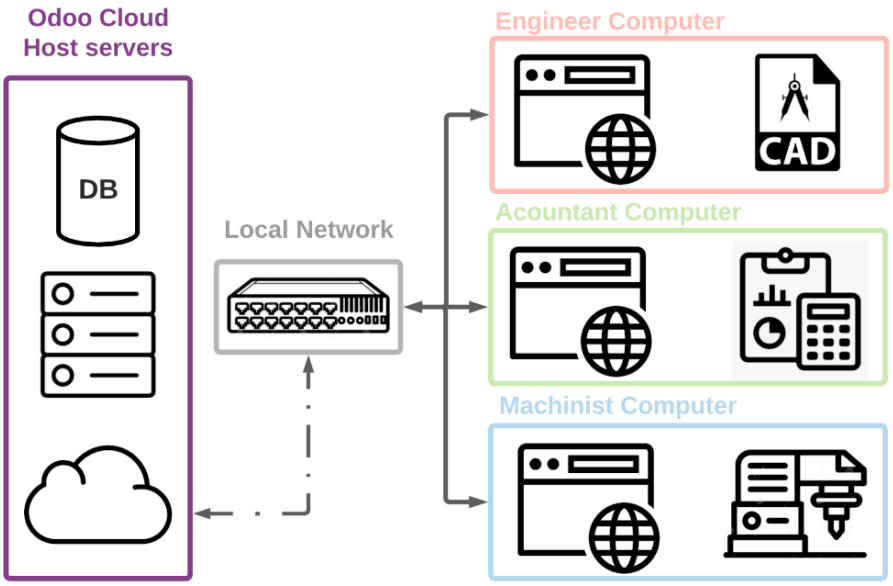

Figure 59 ODOO functional workflow diagram configuration 1

Secondly, users can interact with the system primarily via a graphical user interface (GUI), which allows them to access various modules on a per-user basis. Thus, different users may be subject

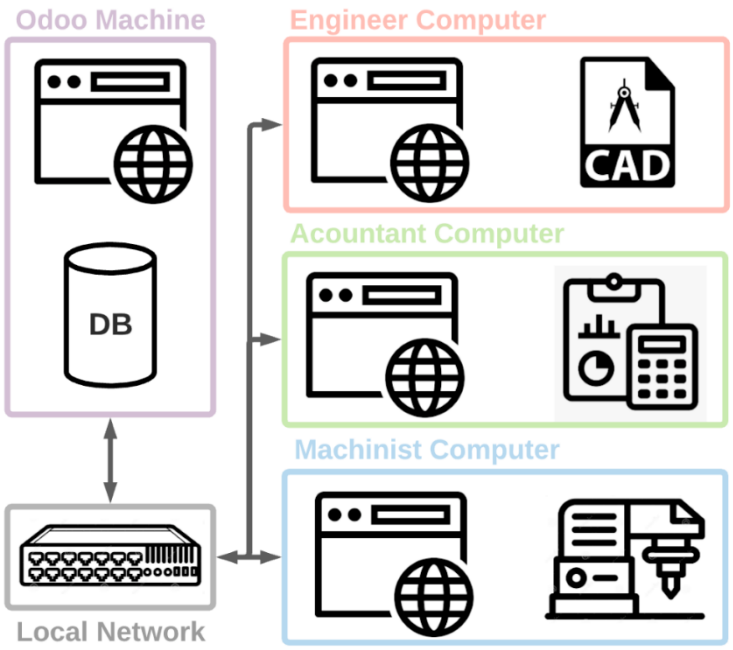

Figure 60 ODOO functional workflow diagram configuration 2

to fine limits to retain control over various areas, depending on business needs. Accounting

modules like sales and inventories would have full access, while entrance to production modules would be severely restricted for the profiles. As a result, the limitation ensures that only department heads have any influence over the procedures.

An example of the many different modules that appear in the GUI is shown as app icons in figure 61 below. The firm supplies all of these applications that can be found in a wide range in the application store, which is loaded with community-made features [3].

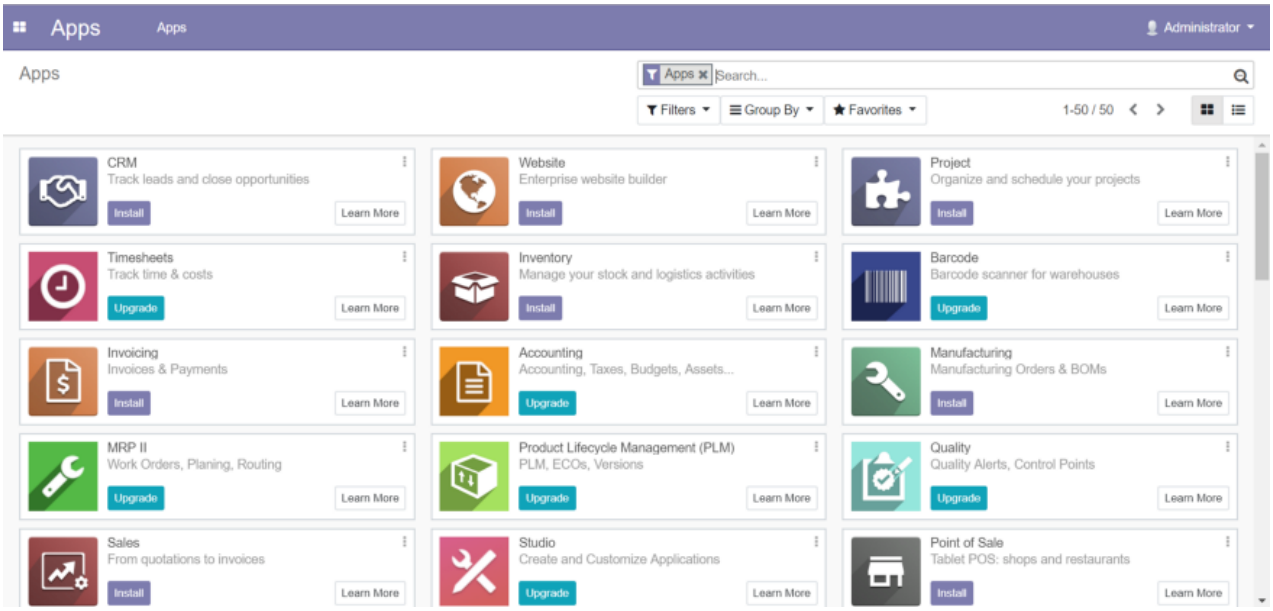

Figure 61 ODOO app store.

20.3 Implementation of integrated MES-PLM-ERP modules in ODOO

With accuracy and utilization of all the needed data provided by the organization, the development of incorporated MES-PLM modules in ODOO is organized. One of the purposes of this thesis is to build the ODOO software's MES, ERP and PLM modules to the best of our ability. As a result, they can keep their current and prospective software processes as close to each other as possible in terms of business practices. MES and PLM implementation begin with identifying who will be in charge of carrying out work on the systems. When numerous users are required, the administrator can create them as needed and allow them access to their account information.

All users share the same Odoo profile, so they can see any updates to work-related data produced by anybody else using the GUI (graphical user interface). So it's a benefit to keeping all users up to date with information filled in by others, and this enables exchanging data and sharing comments very simple if any concern has to be solved. As a result, the issue of information interchange between the design and manufacturing departments is now resolved [3].

20.3.1 Implementation of PLM tools

This PLM software is primarily utilized by a company's design department to input client order information, CAD documents on demand, raw material type, defining the bill of materials, and product routing information. Those apps are illustrated below, in a picture that primarily illustrates all of the necessary applications required for feeding in the data necessary to be stored in the PLM information system. The user accountable for this system uses them.

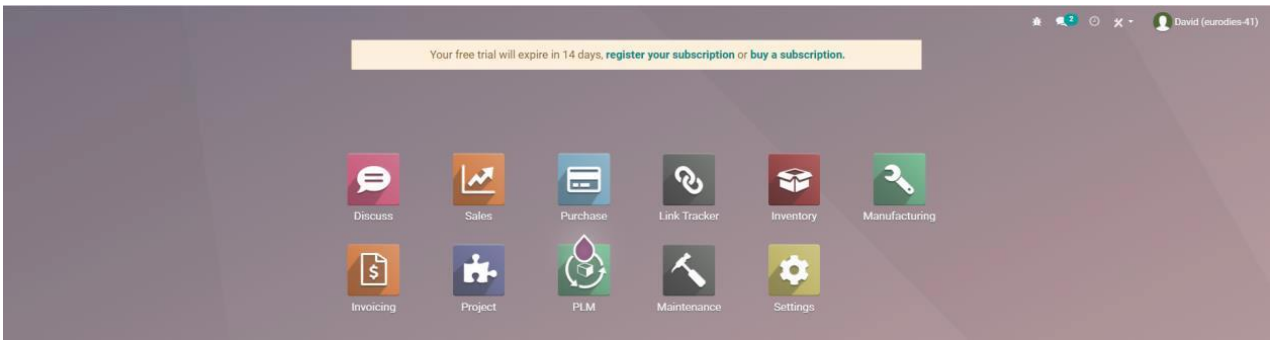

Figure 63 Working interface for PLM user. www.odoo.it

Initially, the PLM enterprise system procedure occurs with the filling out of client request data, product demand information, and the component that will be used to make the product in the sales application. As a result, a CSV file with the necessary data may be imported from the external application (Comma-separated file). As a result of its easy integration, Odoo's import/export capability is both interoperable and user-friendly.

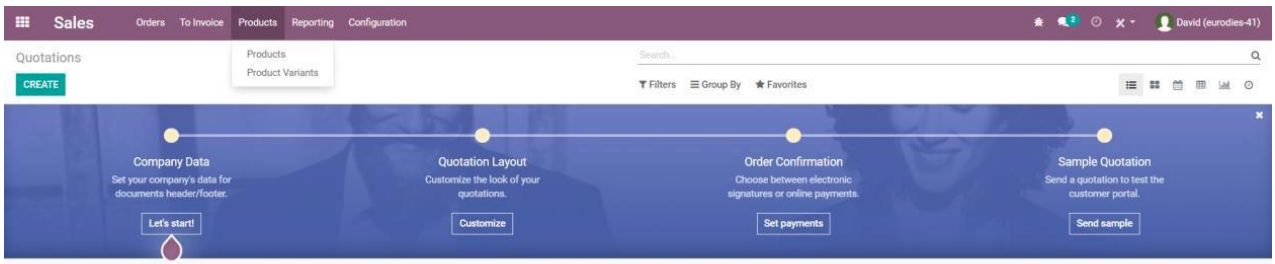

Figure 62 Sales order, Products and Materials

Clicking on the sales application takes the user to the quotes, where they may access or import product and material-related details via the "Product" tab in the upper-left corner of the browser window. For importing data of the product (names, family/subfamily, product packaging, contained amount, the id of the product and units of measurement), information can be downloaded in CSV format directly to share with external partners or other operations. This is the next step: provide details about the client, the required product, the number to be produced, the delivery time, the planned date, and the project stage. The design department needs all the information linked to Cad models and the items on request, so it's all fed into the sales order, which includes all the necessary search tabs.

In the project CSV file, the import entries provide data on the project's sources, client, description, and stage. The project's current phase is orchestrating the operational status for that specific element. Figures like the one below indicate what data may be accessed after users enter the project area. Only authorized users are able to enter this data. Even with the program, a person with project access capabilities may create manually every aspect.

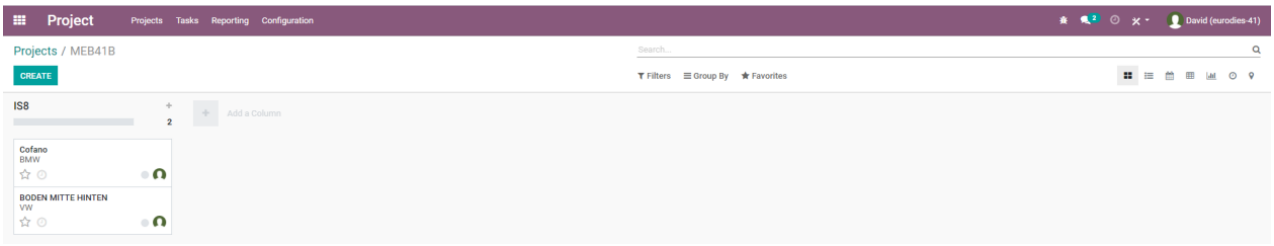

Figure 65 Project phase demonstration.

Work centres, operation sequences, and operations lists are all critical components of PLM. For example, while discussing the definition of product life cycle management, it's critical to provide a representation of the bill of materials along with the routing. As a result, all of the factory's work centres have their data entered and are now in operation.

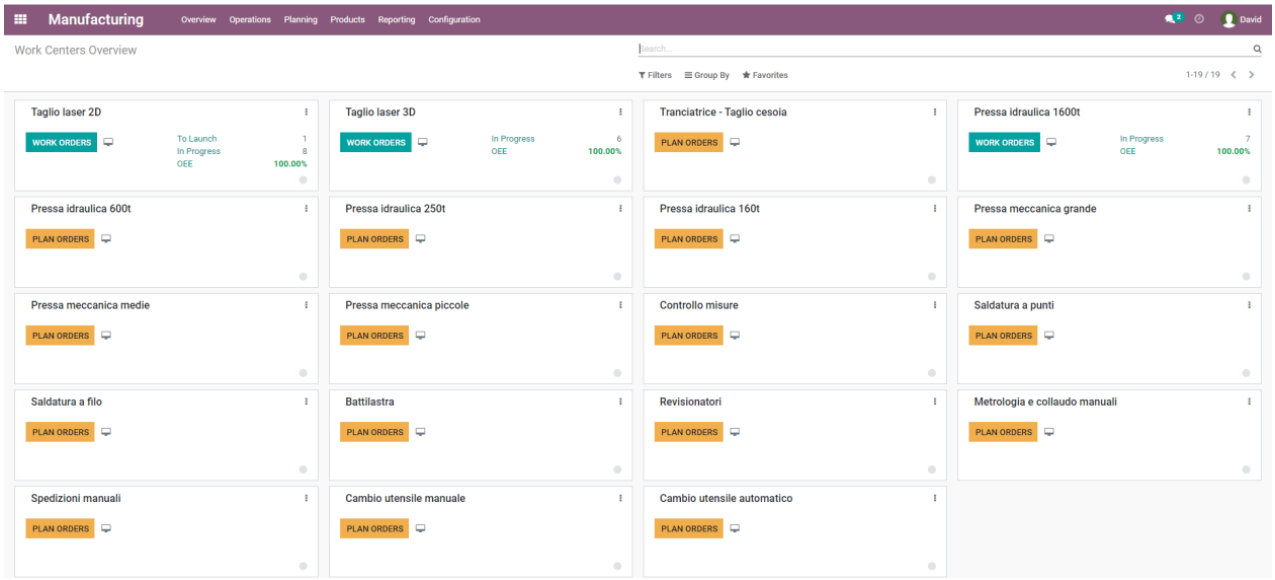

Figure 64 Working centre overview.

The graphic depicting the factory's various machinery and how they may be put to use throughout the manufacturing process is an overview of the factory's work centres. The work centre territory may thus be accessible by both PLM and MES users for the purposes of using it in their own way. Employees of PLM may utilize the work centres to fill up routing and production order data, while MES users can access the work centre area to carry out the work order [3].

20.3.2 Purchase order application

A purchase order is a software entity or tool used to fill inventories with raw materials according to forecasts in the software. In PLM modules, a check start refers to checking for every circumstance before initiating the manufacturing process, which includes raw material availability. That's what raw material availability is referred to as in PLM modules.

The PLM user's dashboard shows the application for the purchase order. To be honest, neither the sales order nor the purchase order belongs in the realm of PLM. Both the sales order and the purchase order contain information on financial and material management, making them major ERP/MRP entities. However, in order to incorporate our data, the program necessitates that every single one is interoperable with the others.

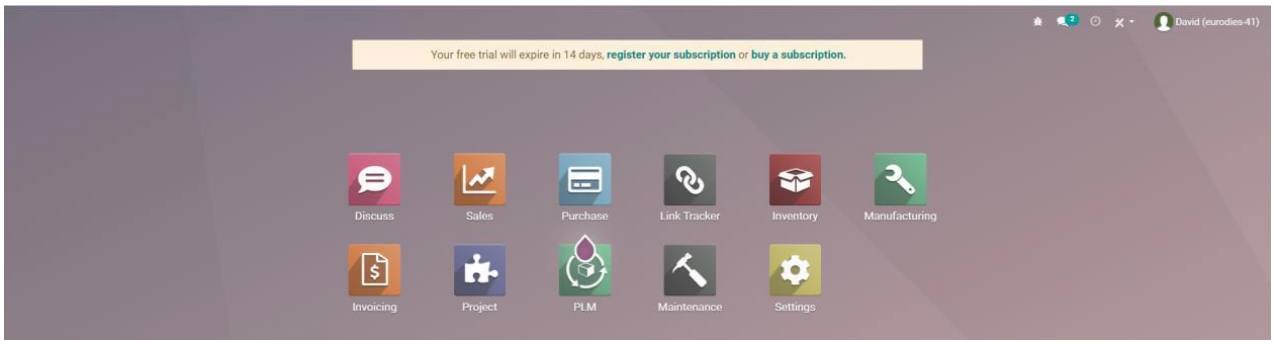

Figure 67 Purchase order application. Image from www.odoo.com

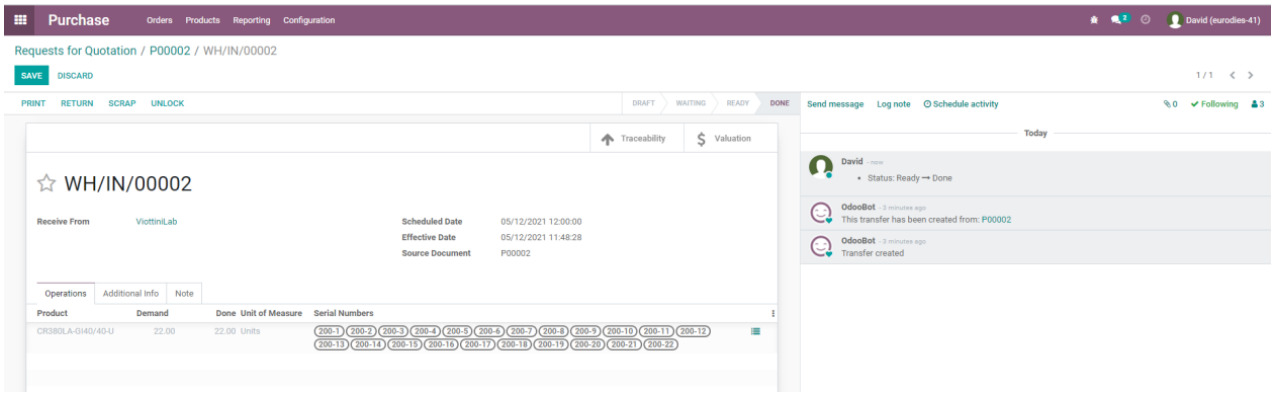

Figure 66 Purchase order info section. Image from www.odoo.com

The purchase includes the seller's details, the product bought from the vendor, the scheduled and actual shipping dates, the amount requested, and the lot/serial number. The buy is made. There's a traceability icon in the upper right corner to show where the product has been, from the customer's completed goods warehouse all the way to the firm's raw materials store.

20.3.3 Manufacturing order application

MES and PLM systems both rely heavily on the manufacturing order feature. The production order, which is prepared by the PLM administrator and executed by the MES user, integrates the

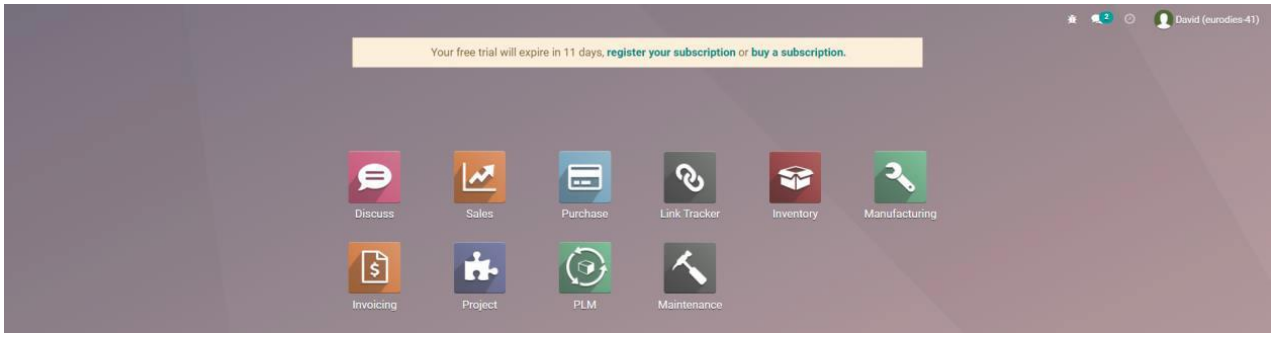

Figure 68 Manufacturing order application

two systems.

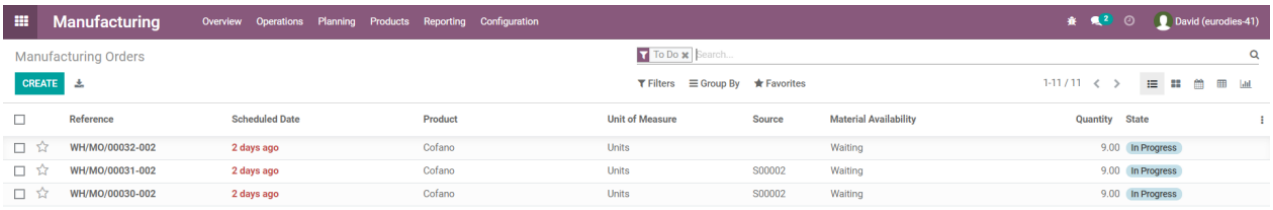

Figure 70 The list for Manufacturing orders. Image from www.odoo.com

Moreover, ODOO's manufacturing order application allows seeing a manufacturing order list including data on the product, the number, product variant, the part, order of operations, bill of material, planned date, and the assignee. The system has also the feature of making a maintenance request of equipment and recording the production processes for further analysis.

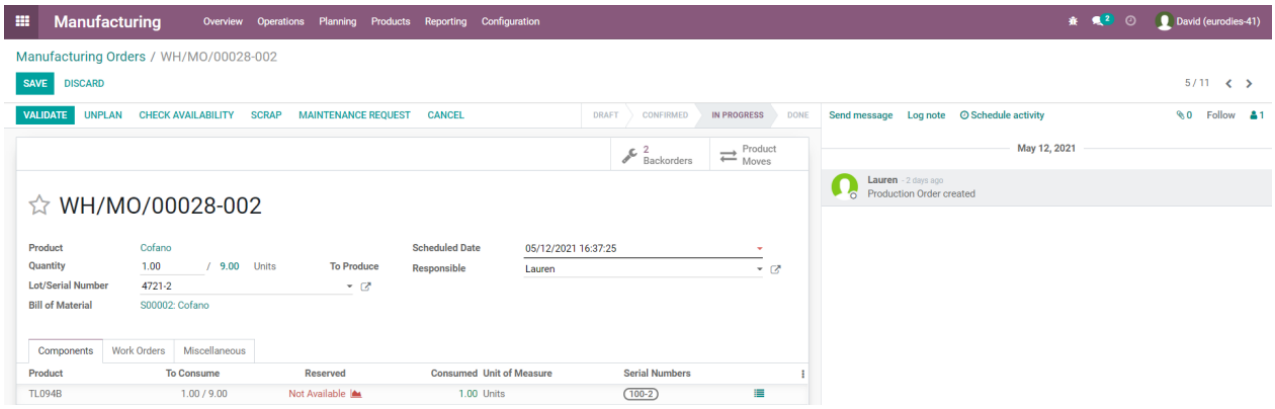

Figure 69 Information section of manufacturing order

For the sake of this example, all machine operations will be done sequentially as shown in Figure 71. Only the MES user allocated to run that machine should be able to perform any activities.

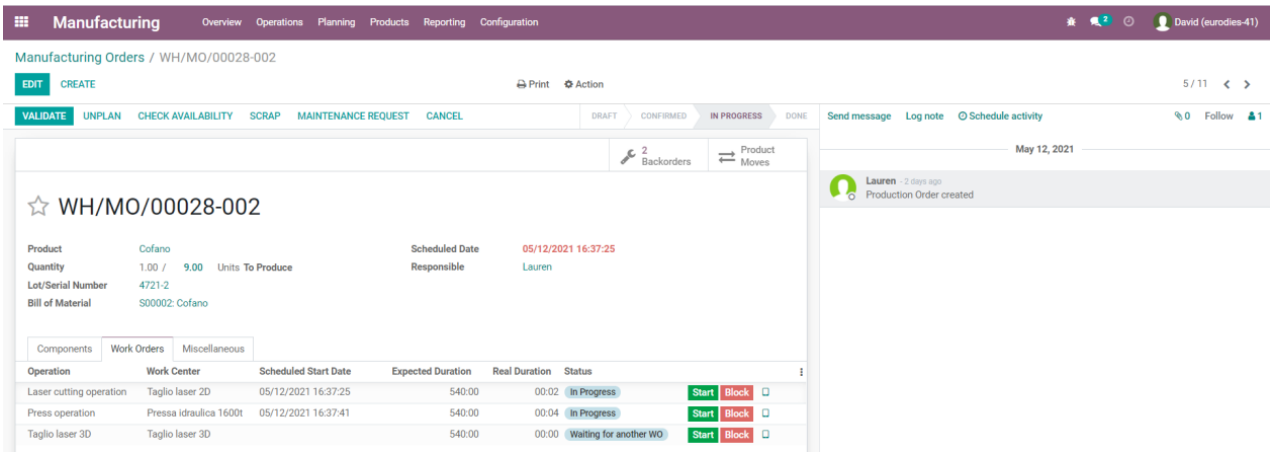

Figure 71 Sequence of operations

20.3.4 PLM application

Because it involves managing the design change management area, the PLM (ECO) is the most critical application for a PLM user. For every request for modification from the customer side, an engineering change order is made. The change can also be asked from the operator's side, for example, if routing or a bill of materials is to be changed.

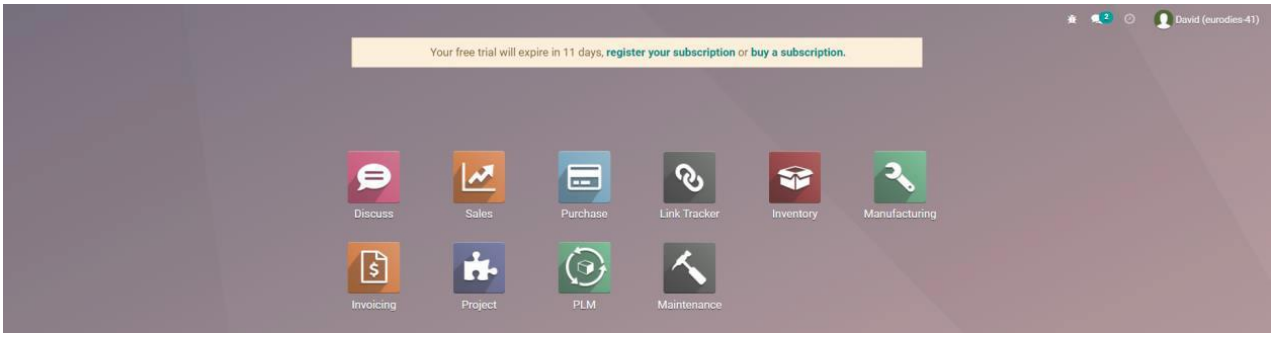

Figure 73 PLM application

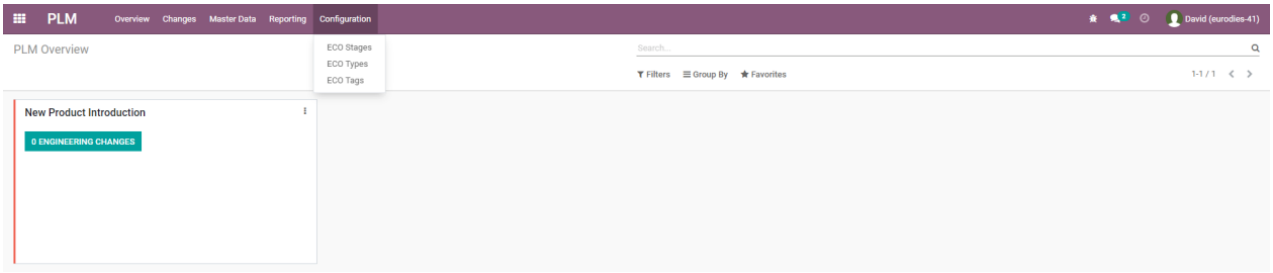

Figure 72 ECO type

Creating an ECO type with the essential data for a change order may be shown in the figure. Only the PLM user can generate an ECO, and the MES user may read one that has been prepared [3].

PART VI: INVESTIGATION OF OBTAINED RESULTS AND CONCLUSION

21. Need for Internet

Utilization of the internet is a necessity as cloud-based Onshape programmes and other similar PLM tools are accessed only through web-browsers and Ios & Android applications. Indeed, it is less costly than using private servers with additional costs. But, even now, the internet is restricted in some parts of the world and there has been a frequency of internet shutdowns due to the absence of good infrastructure or political instabilities. For example, there were political protests against the government in Belarus in 2020 which caused artificial shutdowns by the government in order to eliminate opposition in the country. These restrictions are costly only for the government itself, and they cause

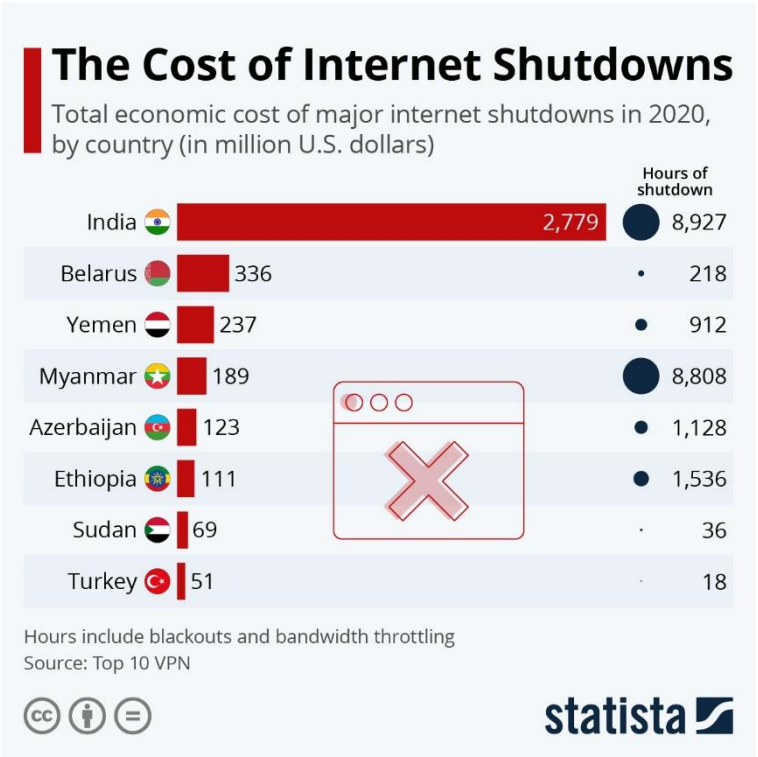

Figure 74 Total cost of Internet shutdowns and hours of shutdown in countries by ranking. Data is from www.statista.com/

the loss of many opportunities [59]. As mentioned above, Onshape cannot deal with such an issue because of its diverse programming infrastructure and capability to be implemented. The company that is implementing such cloud-based tools cannot collaborate with outside firms that are located in the mentioned states, which hinders the progress of PLM operations.

22. Onshape utilization in diverse enterprises and organizations

Since the cloud-based application was generated, it has been attracting several engineering organizations for trials with its multifunctional features. Therefore, for result analysis, direct feedbacks from those firms would be a good conclusion example.

22.1 Garrett Motion

Garrett Motion is the world's leading manufacturer of turbochargers, with products in each vehicle category and for every type of engine.

In order to communicate the most up-to-date design concepts across their five R&D centres, eleven close-to-customer engineering facilities, and thirteen production locations throughout the globe, the international company relies on Onshape's real-time document management system.

According to Garrett's Senior Director of Design Engineering, "Onshape transformed the way we operate by going from a functional team of 200 committed designers to more than 700 individuals who are utilizing (our product models) throughout the engineering sector, the production community, and subcontractors." Garrett's worldwide team of engineers was using on-premise, file-based CATIA at the time of the move to cloud-based Onshape. Experienced engineers are notoriously difficult to bribe into abandoning a platform on which they have spent years working. This isn't really about a tool shift, as workers must realize from the outset. *"It's fundamentally about managing human transformation and involvement," he says. Educating them about the advantages, future prospects and changes to our working methods." In the case of a company that is dispersed around the country with diverse perspectives and ways of doing business, Meade says, "learning how to transition from CAD system A to CAD system B is straightforward"*.

22.2 DHL

DHL, the world's largest logistics firm, serves more than 220 nations and territories. As well as their well-known package delivery services (they send out over 1.5 billion items a year), DHL is also a pioneer in contract packaging for other businesses. For the logistics sector, the DHL Digital Manufacturing Group develops bespoke low-cost, highly adaptable and agile robotic systems. Engineers on the team have been tasked with creating mechanical solutions to satisfy the rising expense of labour and the dwindling supply of manpower. DHL uses Onshape's built-in data management and real-time collaboration capabilities to assist in the design and manufacturing of their automated packing machinery and 3D-printed modular conveyor belts. Engineering teams may go back in time with the help of Onshape's extensive Edit History feature, which keeps account of every modification made to a design throughout time. By possessing an auditing record, users are free to test new ideas without worrying that they'll have to redo the whole thing if they fail. *DHL product development engineer George Walsh explains, "With a press of a button, you can go back weeks or months to an older version." "It's like travelling through time," he said. "Onshape eliminates the need for you to keep track of several revisions of a project. According to Redland Sanders, technical manager of DHL's Digital Manufacturing Group, "with conventional CAD, you have a file and you have to make sure that your nomenclature is extremely*

rigorous and controlled." In other words, it's now part of the design process. Always have the complete timeline of events, and that's huge'' [17].

22.3 OceanGate

An OceanGate submarine transport design and manufacturing business in Seattle has been working with NASA's Marshall Space Flight Center in Huntsville, Alabama, to create a new space systems carbon fibre exterior for the company's 5-person exploration subs. The collaboration has been successful. The main design team of OceanGate consists of four employees based in Seattle and five vendors located in four different locations. Technicians may collaborate on the same design in the cloud using Onshape, and they have access to a full Edit History that shows who performed what modifications and when in real-time. The team may go backwards in time to any point in the design process, utilizing history. OceanGate's Director of Engineering and Marine Operations, Dan Scoville, praises Onshape's collaborative nature. In addition, the CEO appreciates the convenience of the system by saying *''We might both be in the modelling, and he can express his preferences, point out flaws, raise concerns, and make ideas"*[17].

22.4 Kichler Lighting

Kichler Lighting is a world-renowned manufacturer of stylish and cost-effective home lighting fixtures. One of the major reasons Kichler switched to cloud-based Onshape was to address data management difficulties between their scattered design and production staff. However, the previous systems were entirely file-based and only offered 2D solutions. Because of this, they were exchanging sketches with vendors and manufacturers all around the world. Mehul Gala, Senior Product Development Engineer at Kichler, describes the approach as "*burdensom*e" and "*didn't allow for very extensive cooperation.*" For example, sharing product designs with key internal corporate stakeholders who do not typically have access to CAD is now much simpler thanks to Onshape [17].

22.5 Meter during COVID-19

When unavailability for engineers, IT costs, and messaging are all decreased, the design phase may go much faster. The Rise Emergency Ventilator was developed, produced, and experimentally validated in just three weeks by Meter, a San Francisco and Boston-based industrial hardware company — a process that typically would have lasted several months. There were six product versions in just 21 days, and engineers worked unsustainable 18-hour days – yet this feat was only achievable because of real-time cloud cooperation technologies. This is an exceptional example accomplished under COVID-19 crisis pandemic conditions [8]. With six redesigns in three weeks, designers were able to introduce an upgraded version of our Rise Emergency Ventilator every 3.5 days. Each member of the engineering team might observe changes as they occur thanks to Onshape's real-time data management feature. Using a detailed Edit History, managers may go back in time to any previous phase of the project and see exactly who performed what changes and when. Conventional ventilators need specialized parts, machinery, and procedures that cannot be effectively measured and are not meant to be rapidly made. Meter designed a ventilator that can be mass-produced at a lower cost to accommodate changing needs [60].

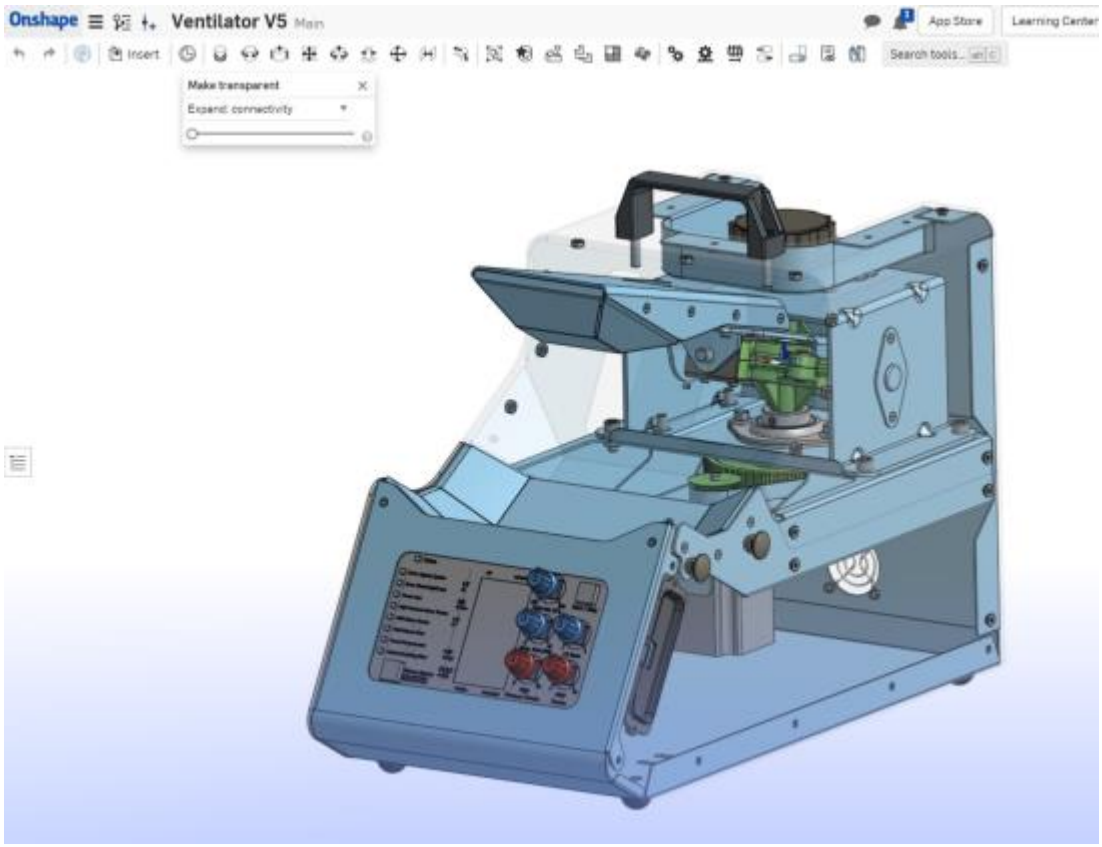

Figure 75 Ventilator design process simultaneously with team. Image from www.onshape.com/

23. Cloud vs Installed PLM/PDM systems

According to the questionnaire, PDM/PLM utilization is more common in organizations with

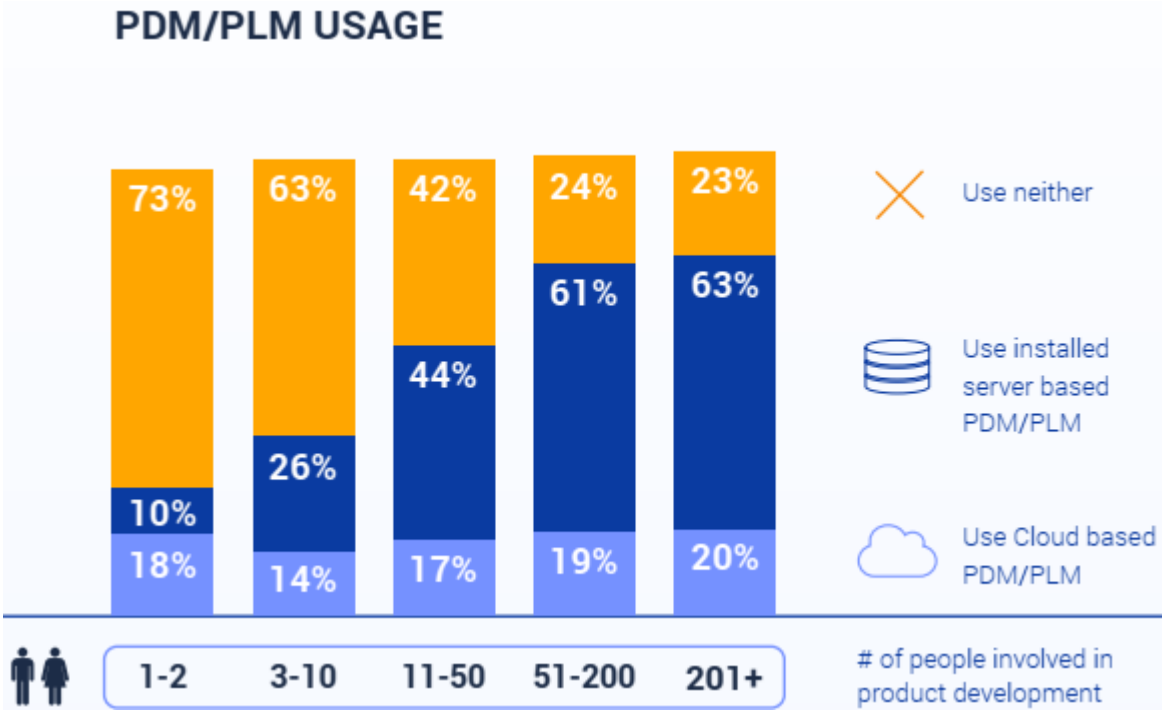

Figure 76 By product development size. Image from 'THE STATE OF PRODUCT DEVELOPMENT & HARDWARE DESIGN 2020'

many locations and big product design teams with more complicated data management demands (Figure 76 & Figure 77).

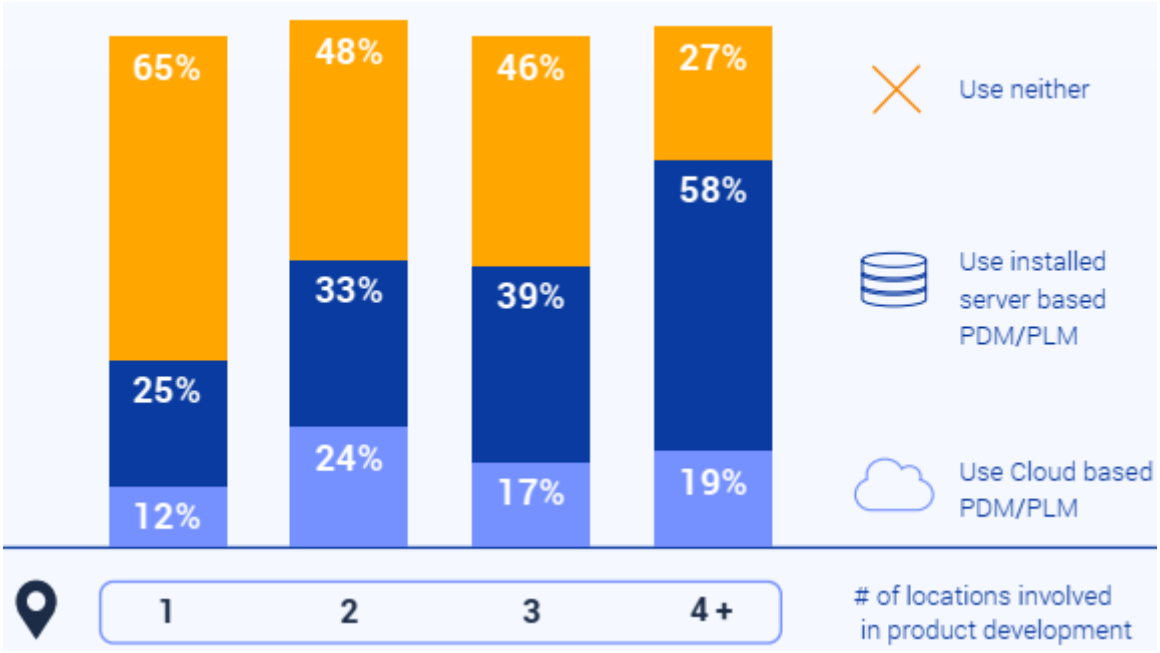

Figure 77 By product development locations. Data from 'THE STATE OF PRODUCT DEVELOPMENT & HARDWARE DESIGN 2020'

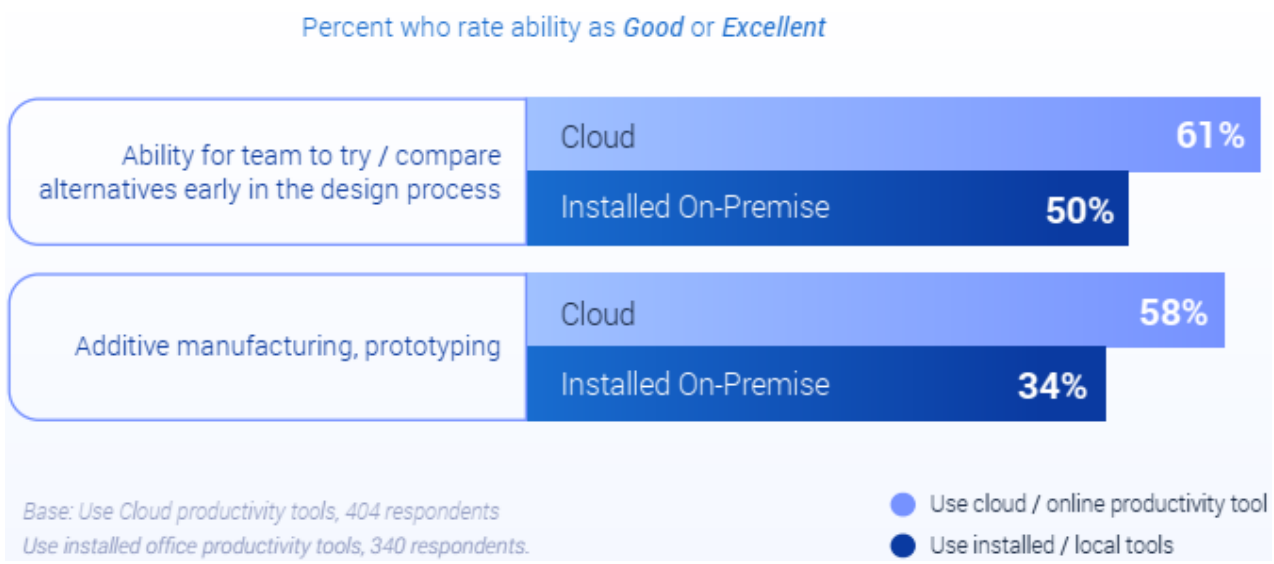

Figure 78 Better capabilities among teams using. Image from 'THE STATE OF PRODUCT DEVELOPMENT & HARDWARE DESIGN 2020'

In the early stages, organizations that employ cloud-based productivity technologies claim improved effective cooperation and better additive manufacturing/prototyping skills (Figure 78).

24. Cloud-based CAD applications in education

Onshape has a modest number of industrial clients, but its potential in academia has yet to be realized. This might be owing to the fact that many universities generally use a conventional, popular CAD program for education and assignments. Onshape offers a benefit over conventional CAD in that versions and preservation are automatically updated in the cloud, ensuring that individuals have the most up-to-date setups. As part of their computer-based tutorials, academic students who study ME50348 Advanced Computer-Aided Design as an aspect of their MSc Engineering Design curriculum were introduced to Onshape and GrabCAD. The youngsters were urged to exchange their CAD drawings with the rest of the world by uploading them to GrabCAD. This has the advantage of allowing the instructor to evaluate and keep track of

the student's continuing CAD progress and revision modifications. This is recommended for coursework among students, but it may not be appropriate for sensitive tasks or class assignments where plagiarism is a concern. The advantages of adopting cloud-CAD cooperatively have yet to be discovered, but it may provide technological challenges for locally and internationally scattered teams collaborating. Global Formula Racing, where two universities (Duale Hochschule BadenWürttemberg-Ravensburg, Germany, and Oregon State University, USA) collaborate to build two racing automobiles to participate in the Formula Student competition, is an indication of good design cooperation between trainees. The squad is presently in first place in the league table. Both the Fusion 360 and Onshape programs have the benefit of using cloud-based online interfaces. Apps will simply require a sophisticated browser (WebGL for Onshape), high-speed internet connectivity, and RAM. It is not essential to have a high-end video card or a large amount of computing power. This allows cloud CAD to be used on any computer in a college without the need for specialized CAD gear, allowing for more mobility and adoption. Autodesk already has a well-established educational license program, and students may use Onshape for free. The pedagogical advantage of this functionality is that CAD may be carried into the lecture room or common room without the need for a dedicated work area or a computer lab [34] [61].

25. Conclusions

As the world evolves and adopts new technology, businesses are striving to improve and automate their operations. How to get there is not specified and relies on a variety of elements, such as the type of customer and the size of the firm. It's no secret that computers and technology have come a long way in the last several generations thanks to the drive for automated systems and advancement. The industry's main desire is to utilise all of the new tools available to enhance and differentiate itself in today's market. Manufacturing information systems are a critical instrument with a broad impact on the organization as a whole. To handle the continuous flow of data generated by a firm and link it to consumers, suppliers, contractors, and other industry participants these platforms are used.

The cloud and software-as-a-a-service (SaaS) are emerging computer platforms, especially in PLM systems. While they may displace some legacy software, they aren't going anywhere any time soon. For software application companies, it is relatively simple to create a hosted version of their products. But to bring these offerings to an external SaaS platform like those offered by cloud service providers, the codes must be rewritten to take advantage of the new functionalities and infrastructure to increase the effectiveness of product development procedures. There are numerous benefits to using SaaS/cloud service and pricing models, but there are also drawbacks for both product providers and consumers. As a result, the shift is expected to be slow and fragmentary, as firms release new versions of existing items that are better suited to the new platform distribution and price model. User apps and data are also highly customized and kept in private databases. The transition to a cloud-based SaaS platform would be difficult for engineering companies, but they could do it incrementally if the economics made more sense.

The main objective is to give methods and insights on how to use Cloud-native or hybrid (in-premise with cloud) software (e.g. ODOO) and its interoperability with MES-PLM-ERP information flow systems in order to develop an integrated model. Furthermore, the results obtained can be extremely beneficial to the company and other engineering firms, as this integration fixes the major issue of data flow between the various levels of the organization, and

their user-friendly interface makes it simple to use without requiring additional time to learn and experiment with it.

By removing the most frequent roadblocks to product design, Onshape's digital services accelerate the design process. In the same way that agility has been critical for software firms in recent years, it is becoming essential for hardware companies as well. A company's capacity to react rapidly in the face of unanticipated or unpredictable circumstances is critical now more than ever before. Transnational product engineering teams may collaborate from anywhere using SaaS CAD and data management solutions. An internet browser or a mobile app (for iOS or Android) enables designers to quickly access their project and modelling applications from any desktop, tablet, or smartphone. In the event of a computer failure, work can proceed on another gadget without interruption. Cloud-native product development technologies enable technical teams to collaborate as if they were in the same hall, even if they are located on separate storeys, in different buildings, in other states, or in various regions. Numerous engineers may work on the same 3D CAD model at the same time and offer rapid feedback as simple as writing a comment on social networks, unlike file-based conventional CAD and PDM platforms.

Overall, effective training of engineers and continuous practice implementation of cloud-based applications will lead to a significant decrease in resource usage and acceleration of product development, even though the platforms require connection to the internet. Indeed, the new cloud-native platforms that support the PLM system are not perfectly coded and they require time and resources to improve the effectiveness of the whole system. Moreover, there are also other integrated or connected cloud apps for supporting product development and manufacturing processes, but due to lack of resources, they were not analysed in-depth to give solutions to problems in the PLM framework.

Reference

[1] C. Scott, *Product life-cycle management*, vol. 9, no. SUPPL. 9. 2011.

[2] T. Edition, *Personal- entwicklung*. .

[3] P. Rb and R. Universitario, “Politecnico di Torino Politecnico di Torino,” p. 87316161, 2020.

[4] S. Hill Jr, “A winning solution,” *Manuf. Bus. Technol.*, pp. 1–4, 2006, [Online]. Available: https://www.plm.automation.siemens.com/zh_cn/Images/MBT_Lockheed-Martin_CoverStory_eprint_tcm78-3190.pdf.

[5] L. Javvadi, “Product life cycle management An introduction,” 2011, Accessed: Aug. 23, 2021. [Online]. Available: https://www.researchgate.net/publication/285769844_Product_life_cycle_management_An_introduction.

[6] M. Cantamessa and F. Montagna, *Management of innovation and product development: Integrating business and technological perspectives*. 2015.

[7] W. F. C. Need, “An Introduction to Agile Product Design.”

[8] Engineering.com, “The State of Product Development & Hardware Design 2019,” pp. 1–26, 2019, [Online]. Available: https://www.engineering.com/ResourceMain.aspx?resid=939.

[9] *Информационно - коммуникационное пространство и человек*. 2012.

[10] “(PDF) Floating License Management.” https://www.researchgate.net/publication/273573932_Floating_License_Management (accessed Sep. 13, 2021).

[11] Onshape, “The Engineering Leader’s Guide to PDM & Data Management,” p. 44, 2019.

[12] “Solving The Top 5 PDM & Data Management Problems.” https://www.onshape.com/en/resource-center/videos/solving-the-top-5-pdm-data-management-problems (accessed Sep. 19, 2021).

[13] A. Lella, “Smartphone Usage Has Doubled in the Past Three Years - comScore, Inc,” *27-01-2017*, 2017. https://www.comscore.com/lat/Prensa-y-Eventos/Blog/Smartphone-Usage-Has-Doubled-in-the-Past-Three-Years (accessed Aug. 24, 2021).

[14] P. Agarwal, “Continuous SCRUM: Agile management of SAAS products,” *Proc. 4th India Softw. Eng. Conf. 2011, ISEC’11*, pp. 51–60, 2011, doi: 10.1145/1953355.1953362.

[15] M. M. Meeshi, V. N. Kulkarni, V. N. Gaitonde, G. J. Satish, and B. B. Kottürshettar, “A review on PLM platform deployment in aerospace industries,” *AIP Conf. Proc.*, vol. 2358, no. July, 2021, doi: 10.1063/5.0057962.

[16] M. H. Holmes and M. H. Holmes, “An Introductory Guide to Maple,” *Sci. York*.

[17] “Beyond Data Management: How Engineering Leaders are Turning Data into Insights.”

[18] Y. Kayir and M. Er, “The Effect of The CAD Data Exchange on the Motion Analysis in the Solidworks CAD Program,” *Aksaray Univ. J. Sci. Eng.*, vol. 3, no. 1, 2019, doi: 10.29002/asujse.540797.

[19] “The Pros and Cons of 8 Popular Databases - KeyCDN.” https://www.keycdn.com/blog/popular-databases (accessed Oct. 13, 2021).

[20] M. Cusumano, “Cloud computing and SaaS as new computing platforms,” *Commun. ACM*, vol. 53, no. 4, pp. 27–29, 2010, doi: 10.1145/1721654.1721667.

[21] H. Panetto, M. Dassisti, and A. Tursi, “ONTO-PDM: Product-driven ONTOlogy for Product Data Management interoperability within manufacturing process environment,” *Adv. Eng. Informatics*, vol. 26, no. 2, pp. 334–348, 2012, doi: 10.1016/j.aei.2011.12.002.

[22] A. Tursi, H. Panetto, G. Morel, and M. Dassisti, “Ontological approach for product-centric information system interoperability in networked manufacturing enterprises Ontological approach for product-centric information system interoperability in networked manufacturing enterprises ONTOLOGICAL APPROACH FOR PRODUCTS-CENTRIC INFORMATION SYSTEM INTEROPERABILITY IN NETWORKED MANUFACTURING ENTERPRISES,” *Annu. Rev. Control*, vol. 33, no. 2, 2009, doi: 10.1016/j.arcontrol.2009.05.003ï.

[23] A. Graesser, “Implementation of Cloud Applications,” pp. 87–104, 2019, doi: 10.1007/978-3-030-14219-3_4.

[24] G. Carlin, S. Things, and T. Of, “Orienting in the cloud universe.”

[25] P. Mell and T. Grance, “The NIST Definition of Cloud Computing Recommendations of the National Institute of Standards and Technology,” doi: 10.6028/NIST.SP.800-145.

[26] L. Savu, “Cloud computing: Deployment models, delivery models, risks and research challanges,” *2011 Int. Conf. Comput. Manag. CAMAN 2011*, 2011, doi: 10.1109/CAMAN.2011.5778816.

[27] E. Castro-Leon and R. Harmon, “Cloud Computing as a Service,” *Cloud as a Serv.*, pp. 3–30, 2016, doi: 10.1007/978-1-4842-0103-9_1.

[28] “(PDF) Planning and Implementing a Network Solution with a cloud application.” https://www.researchgate.net/publication/350955539_Planning_and_Implementing_a_Network_Solution_with_a_cloud_application (accessed Aug. 26, 2021).

[29] M. Nassar, A. Erradi, and Q. M. Malluhi, “Paillier’s encryption: Implementation and cloud applications,” *2015 1st Int. Conf. Appl. Res. Comput. Sci. Eng. ICAR 2015*, Nov. 2015, doi: 10.1109/ARCSE.2015.7338149.

[30] D. Tuncalp, “Management of Privacy and Security in Cloud Computing,” *Web-Based Serv.*, no. March, pp. 1585–1610, 2015, doi: 10.4018/978-1-4666-9466-8.ch070.

[31] S. K. Naidu, K. A. Ayub, and S. Revathy, “Literature Survey of Role Policy Access Using Cloud,” *Proc. 2nd Int. Conf. Trends Electron. Informatics, ICOEI 2018*, no. Icoei, pp. 232–236, 2018, doi: 10.1109/ICOEI.2018.8553790.

[32] S. Souidi, P. Council, and S. Mierzwa, “Cloud Solution Data Science COVID-19 Dashboard Cloud Security Alliance - New Jersey,” no. July, 2021.

[33] “SCRUM Development Process - Springer.” https://www.researchgate.net/publication/346955542_Scrum_Development_Process (accessed Sep. 14, 2021).

[34] J. Barrie, “Applications for cloud-based cad in design education and collaboration,” *Proc. 18th Int. Conf. Eng. Prod. Des. Educ. Des. Educ. Collab. Cross-Disciplinarity, E PDE 2016*, no. September, pp. 178–183, 2016.

[35] “Data Management | Onshape Cloud Product Development Software.” https://www.onshape.com/en/features/product-data-management (accessed Sep. 22, 2021).

[36] “Part Studio | Onshape Cloud Product Development Software.” https://www.onshape.com/en/features/parts (accessed Sep. 23, 2021).

[37] “Using Analytics Enterprise.” https://www.onshape.com/en/resource-center/videos/using-analytics-enterprise (accessed Sep. 19, 2021).

[38] “Onshape | Product Development Platform.” https://www.onshape.com/en/security (accessed Sep. 20, 2021).

[39] “Bill of Materials | Onshape Cloud Product Development Software.” https://www.onshape.com/en/features/bill-of-materials (accessed Sep. 21, 2021).

[40] “App Store - Onshape.” https://appstore.onshape.com/apps/Data Management/IL7KBBHCXND3CH46RW7HUVIFVDJ2O6UM2L3EOUI=/description (accessed Sep. 29, 2021).

[41] “App Store - Onshape.” https://appstore.onshape.com/apps/Data Management/OR2Q3CQMIUVHUKAWN65HJ6UAEOGEDQGSZTDAJCI=/description (accessed Sep. 26, 2021).

[42] “OneIPM.” https://oneipm.com/ (accessed Oct. 14, 2021).

[43] “App Store - Onshape.” https://appstore.onshape.com/apps/Data Management/LEXUN4JA5IDDG56HOPNADPKGN7U4AJFLH6R6KLY=/description (accessed Sep. 26, 2021).

[44] “App Store - Onshape.” https://appstore.onshape.com/apps/Design & Documentation/PTEX5DUHZZPNOGPZ3OXSZI4DXDGL43P4TMENGGY=/description (accessed Sep. 28, 2021).

[45] “Create online instruction and service manuals from your CAD data.” https://www.cadasio.com/?source=onshape-app-store (accessed Oct. 14, 2021).

[46] “App Store - Onshape.” https://appstore.onshape.com/apps/Data Management/5WMOI4S2ZEMWPZZGCSIB66SVUUOILOMOBPWJP4Q=/description (accessed Sep. 28, 2021).

[47] “Assembly Planning App | DM LinkUp.” https://dmlinkup.com/assemblyplanning/ (accessed Sep. 29, 2021).

[48] “App Store - Onshape.” https://appstore.onshape.com/apps/Simulation/WK4WRLFPAIWTGRIPXTAYN5YJMMSIL7IG75LMOCA=/description (accessed Sep. 30, 2021).

[49] “Simulation Tutorials | OnScale Solve Help.” https://onscale.com/help/solve/tutorials/ (accessed Oct. 14, 2021).

[50] “App Store - Onshape.” https://appstore.onshape.com/apps/Data Management/JMRLHGAIKRKN2YYW5RVGAUIE7JYIXZ6I6EUYN3A=/description (accessed Oct. 04, 2021).

[51] “Onshape | Duro.” https://www.durolabs.co/integration/onshape/ (accessed Oct. 14, 2021).

[52] “App Store - Onshape.” https://appstore.onshape.com/apps/Rendering/P22A6LETENGBFNT5A2VGSTU3S6WBRLDX2C2R5UI=/description (accessed Oct. 04, 2021).

[53] “ARbase: Augmented Reality app for Onshape.” https://arbase.io/#how_to (accessed Oct. 14, 2021).

[54] “App Store - Onshape.” https://appstore.onshape.com/apps/Design & Documentation/BI4NF3BZAEQXBXOERCYO6NSHJ5Z62TB6ZI472VA=/description (accessed Oct. 08, 2021).

[55] “Phi | Surface Modeling Reinvented.” https://phi3d.com/updates (accessed Oct. 14, 2021).

[56] “Phi | Surface Modeling Reinvented.” https://phi3d.com/ (accessed Oct. 08, 2021).

[57] “App Store - Onshape.” https://appstore.onshape.com/apps/Utilities/DFE73AMQ42NPMVAEQBQVP56QGLCWJ4ALJUBEBLA=/description (accessed Oct. 08, 2021).

[58] “App Store - Onshape.” https://appstore.onshape.com/apps/Data Management/F6U5XSR2NAJY2QW4VTB3GSPCUNOF42XYEAOHNQQ=/description

(accessed Oct. 14, 2021).

[59] "• Chart: The Cost of Internet Shutdowns | Statista." https://www-statista-com.ezproxy.biblio.polito.it/chart/23864/estimated-cost-of-internet-shutdowns-by-country/ (accessed Sep. 24, 2021).

[60] "How an Emergency Ventilator was Built in 21 Days." https://www.onshape.com/en/resource-center/innovation-blog/how-an-emergency-ventilator-was-built-in-21-days (accessed Oct. 16, 2021).

[61] K. N. Leipold, "CAD for College: Switching to Onshape for Engineering Design CAD for College: Switching to Onshape for Engineering Design Tools Tools," Accessed: Oct. 15, 2021. [Online]. Available: https://scholarworks.rit.edu/other.